The AMS Magnet

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The AMS Magnet

A state of the art superconducting magnet for the Alpha Magnetic Spectrometer.

May 2003

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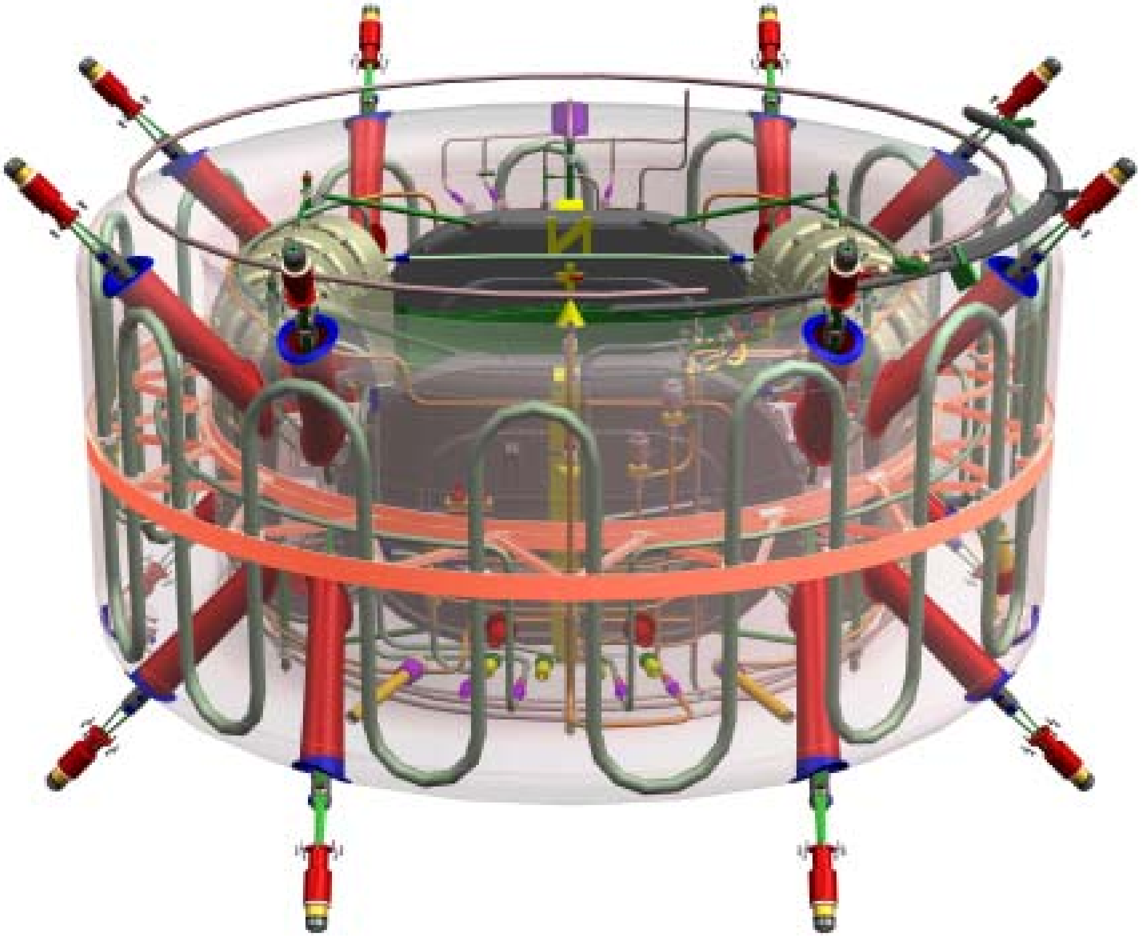

Overview of the magnet system

- Magnetics
- Cryogenics
- Mechanics
- Electronics
- Operations

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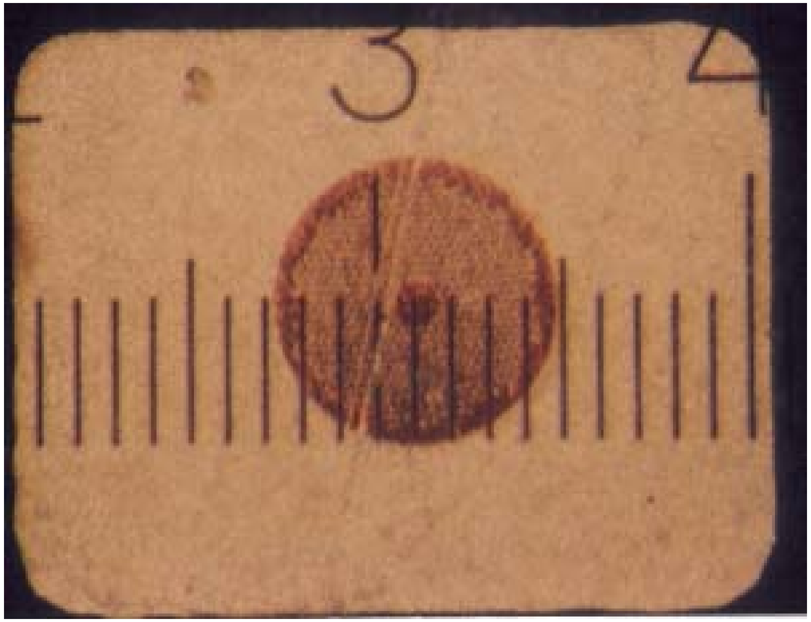
Magnetics

Superconducting wire

Arrangement of coils

Magnetic fields

Superconducting wire (1)



NbTi superconducting filaments

Copper matrix

High-purity aluminium cladding

Superconducting Wire (2)

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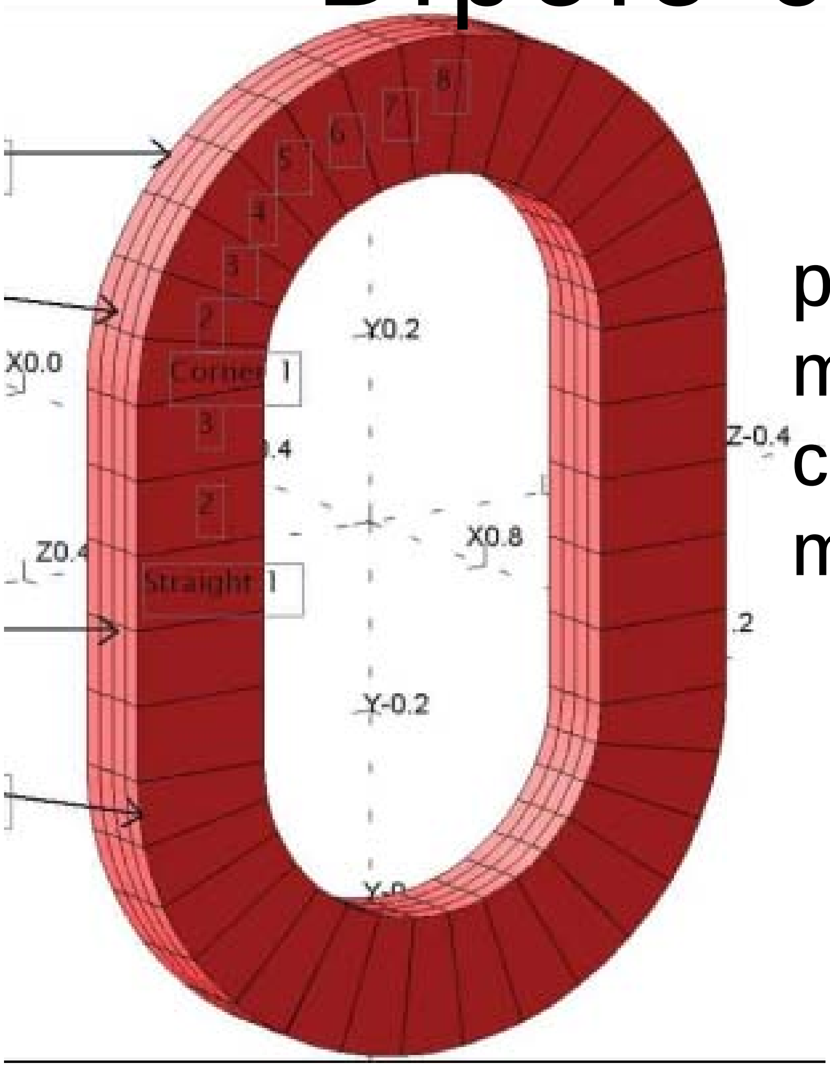
Dipole coil (1)



Two large coils provide the main magnetic field component across the magnet bore.

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Dipole Coil (2)

The first dipole coil being wound.

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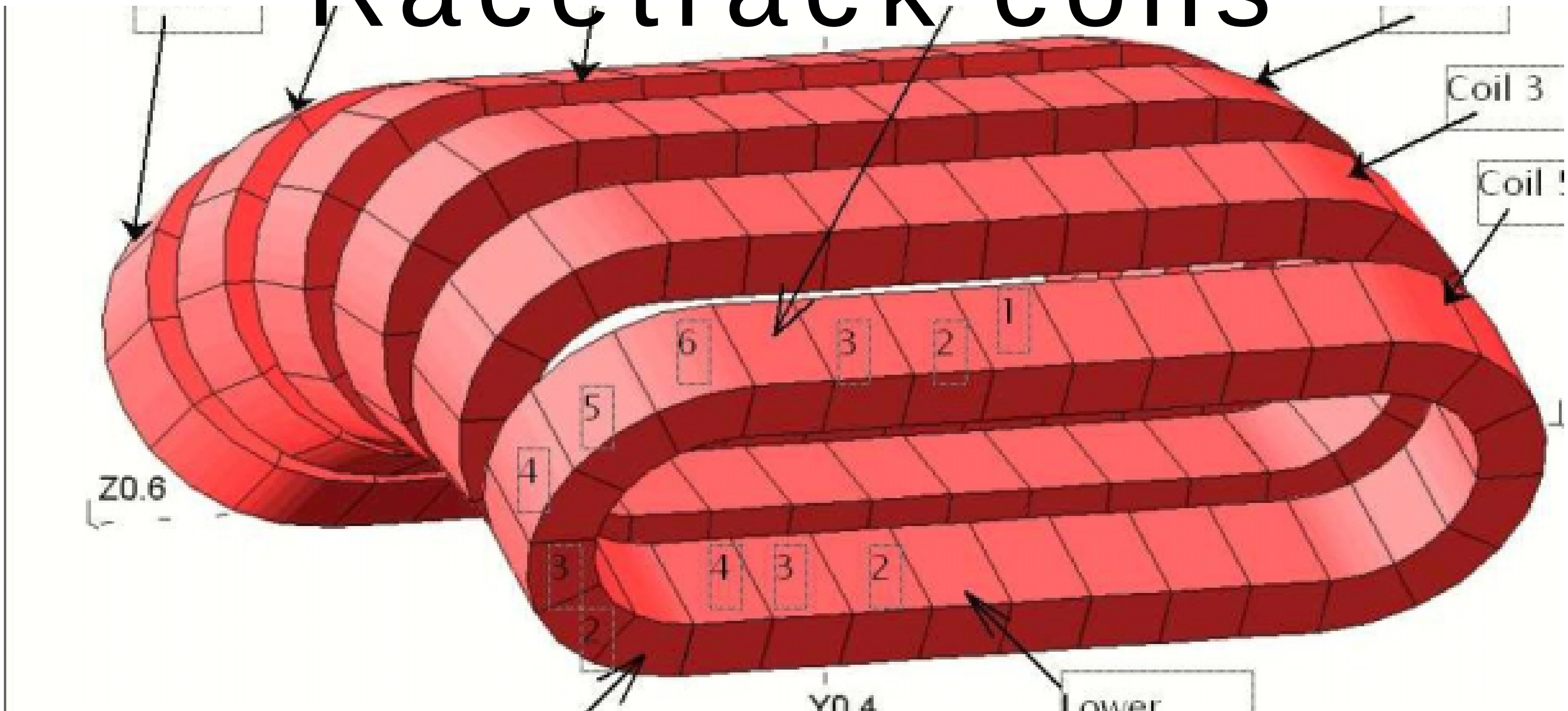
Racetrack coils



- Two sets of 6 racetracks
  - Increased dipole field
  - Reduced external field

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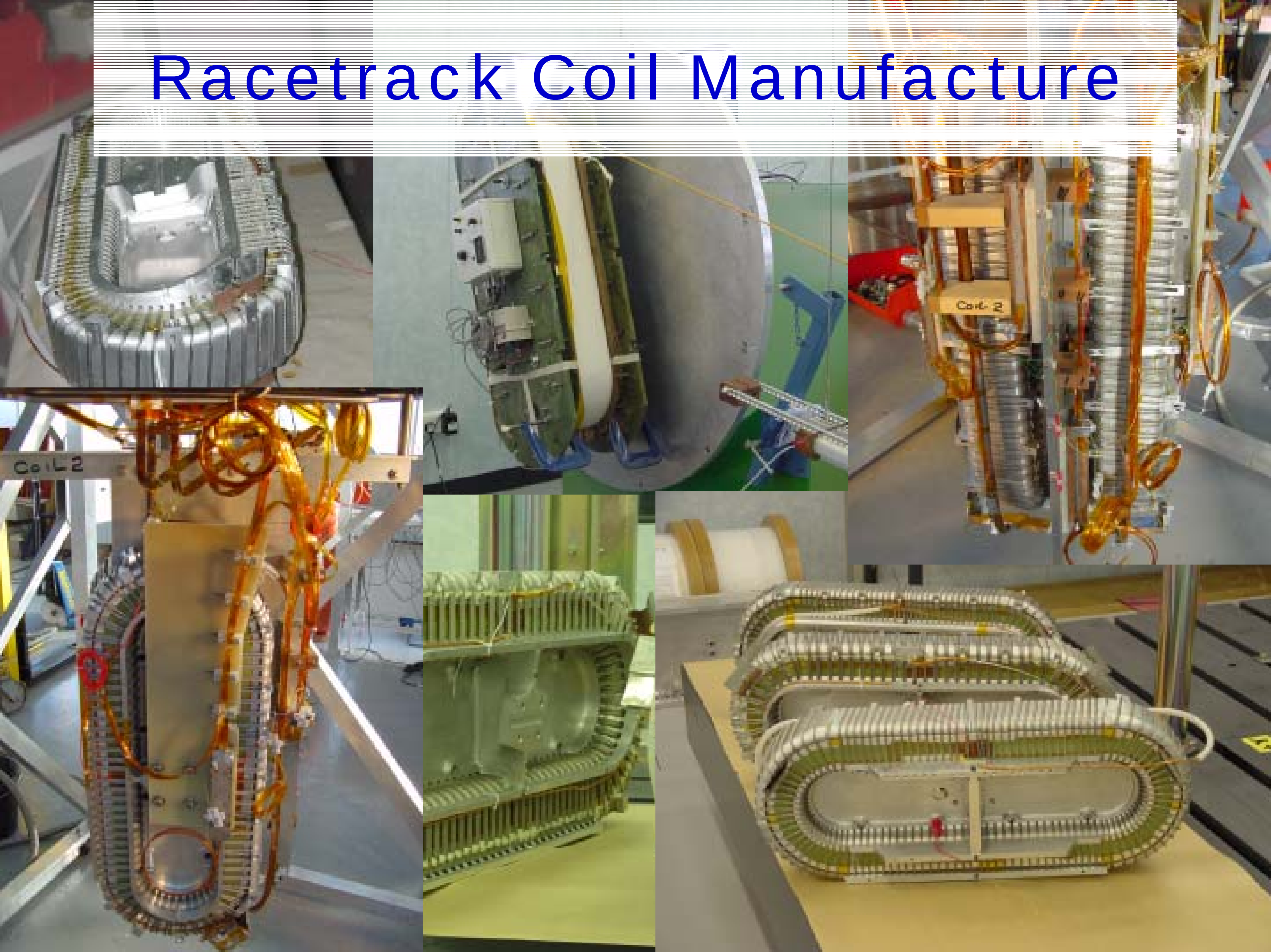
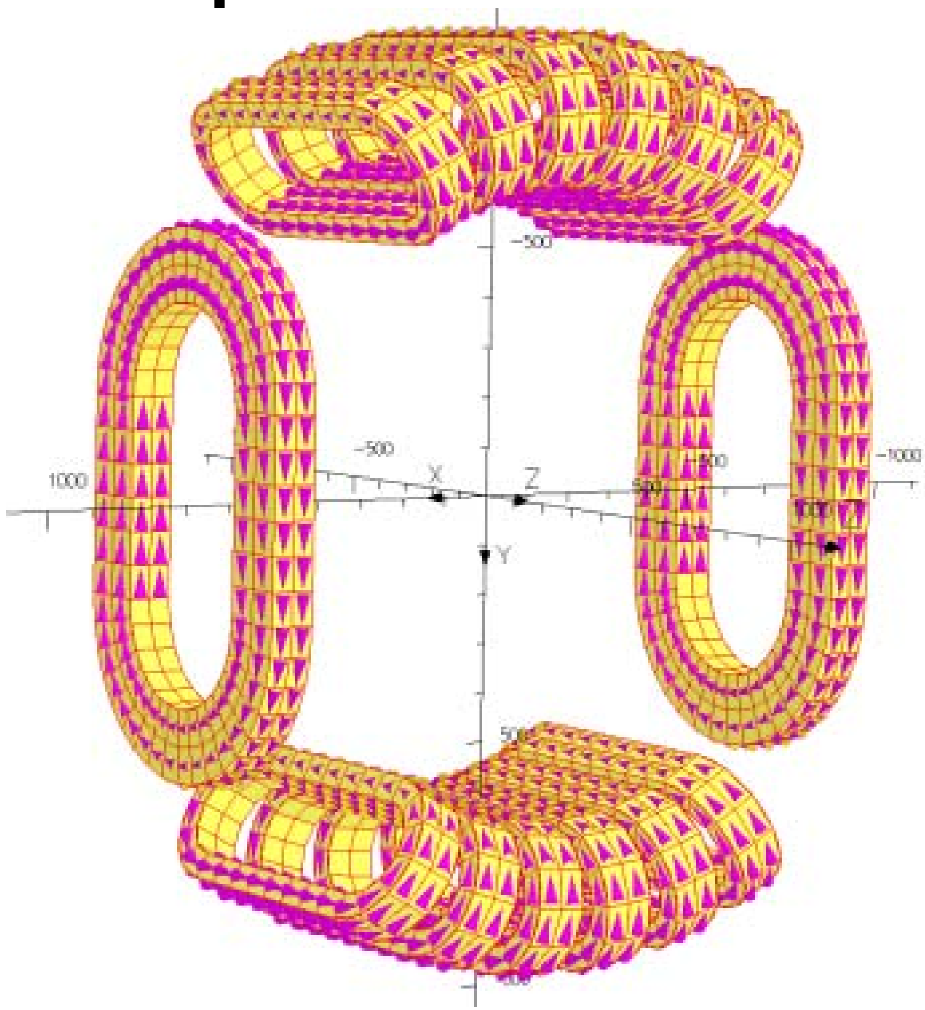
Racetrack Coil Manufacture



Juxtaposition of coils



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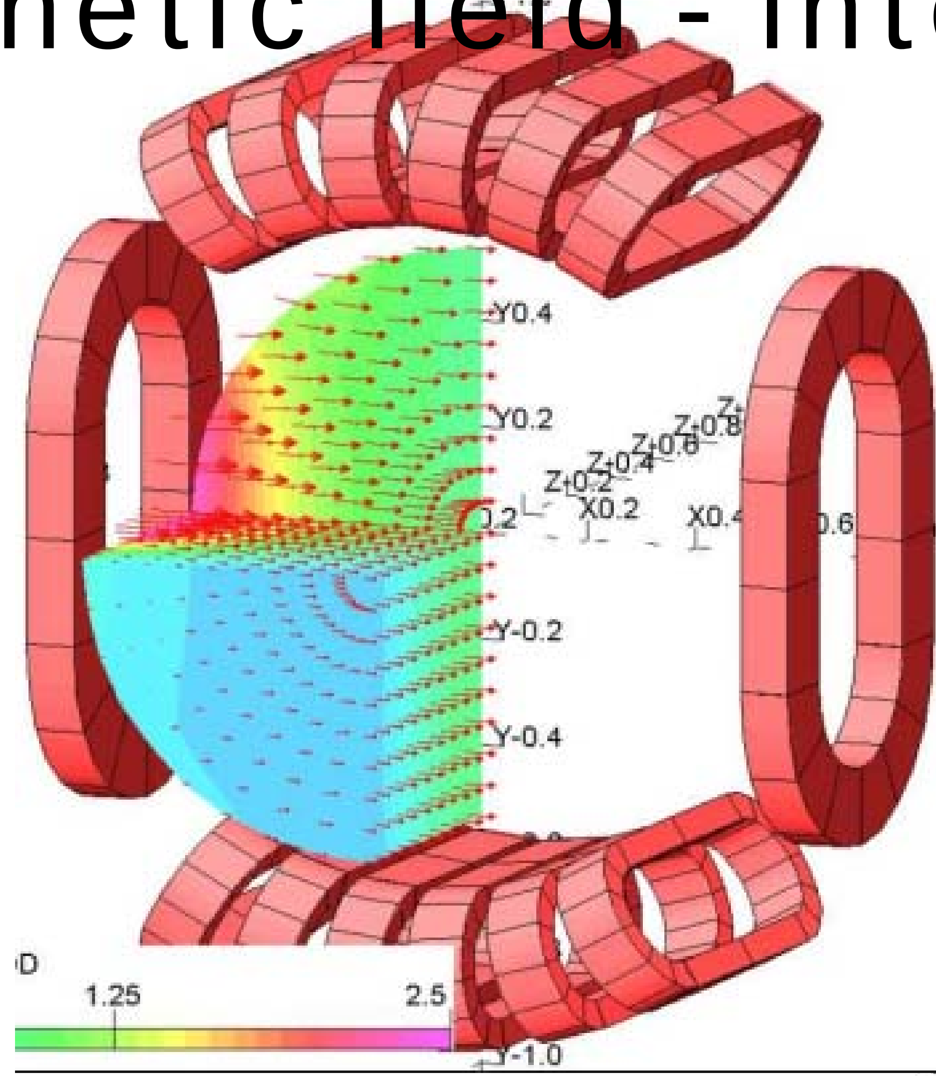
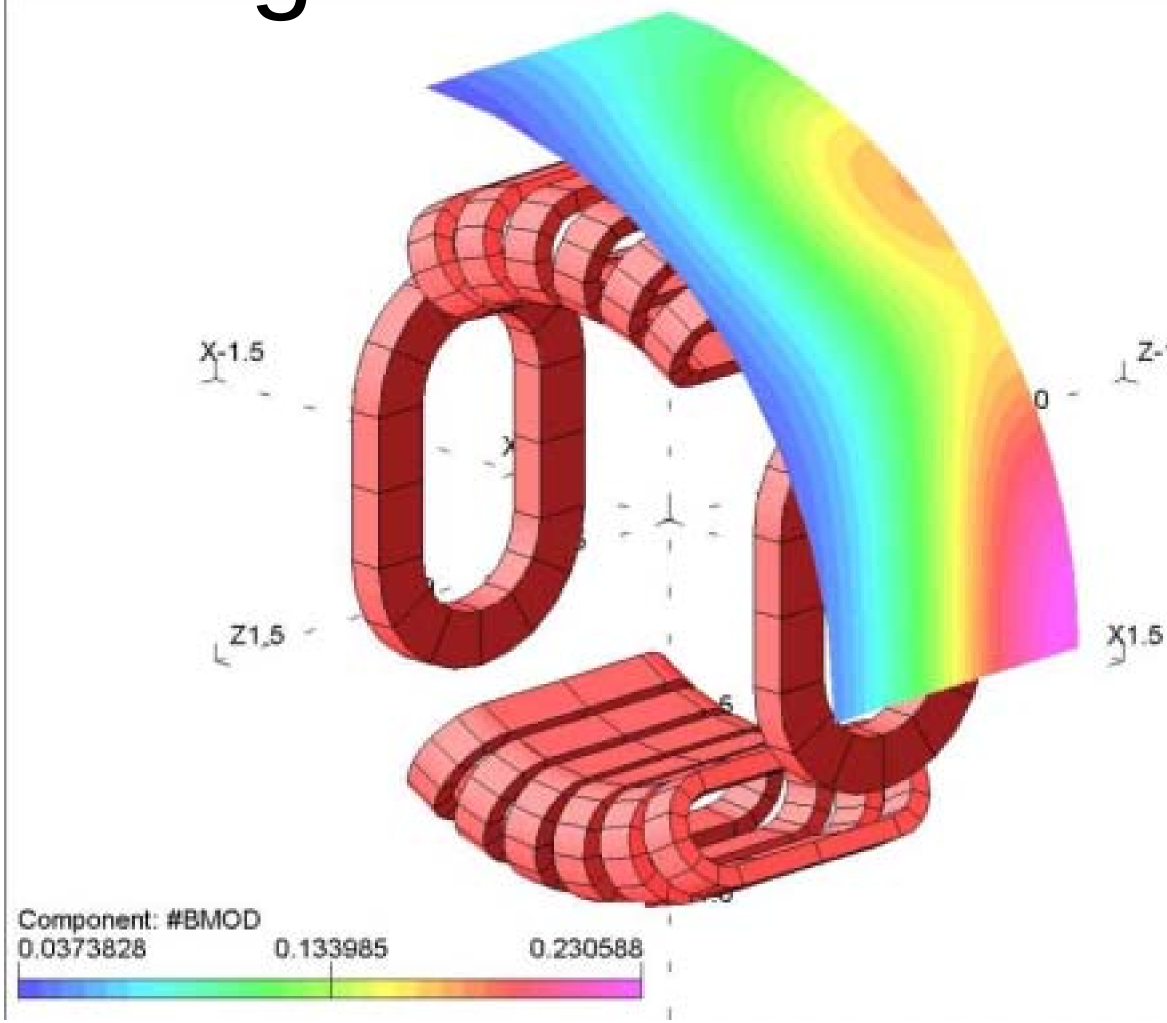
Magnetic field - internal



Magnetic field - external



Magnetic field at the surface of the vacuum case.

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Cryogenics

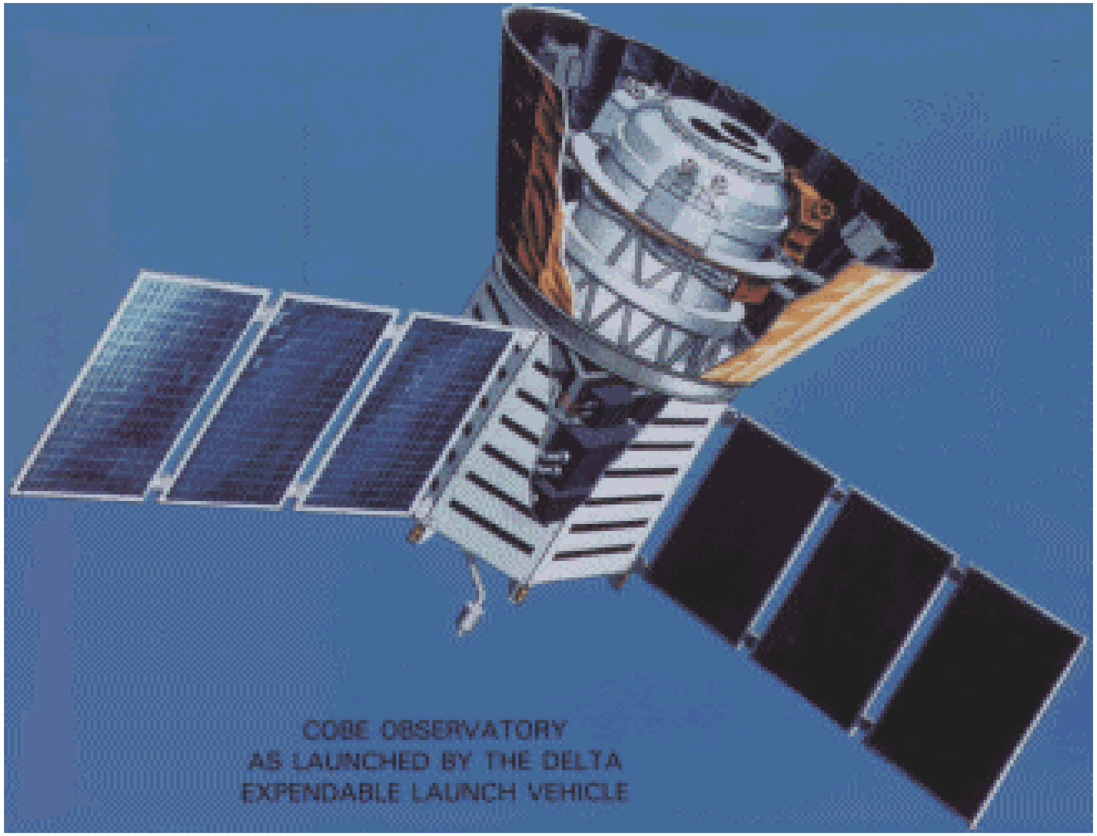
Superfluid helium storage and handling

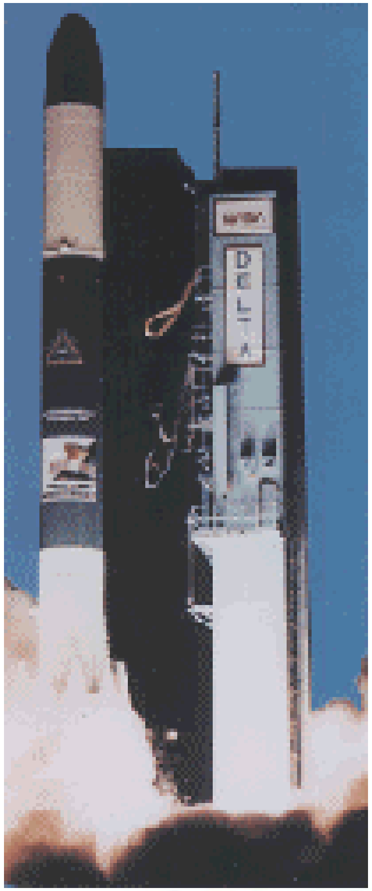
Coil cooling

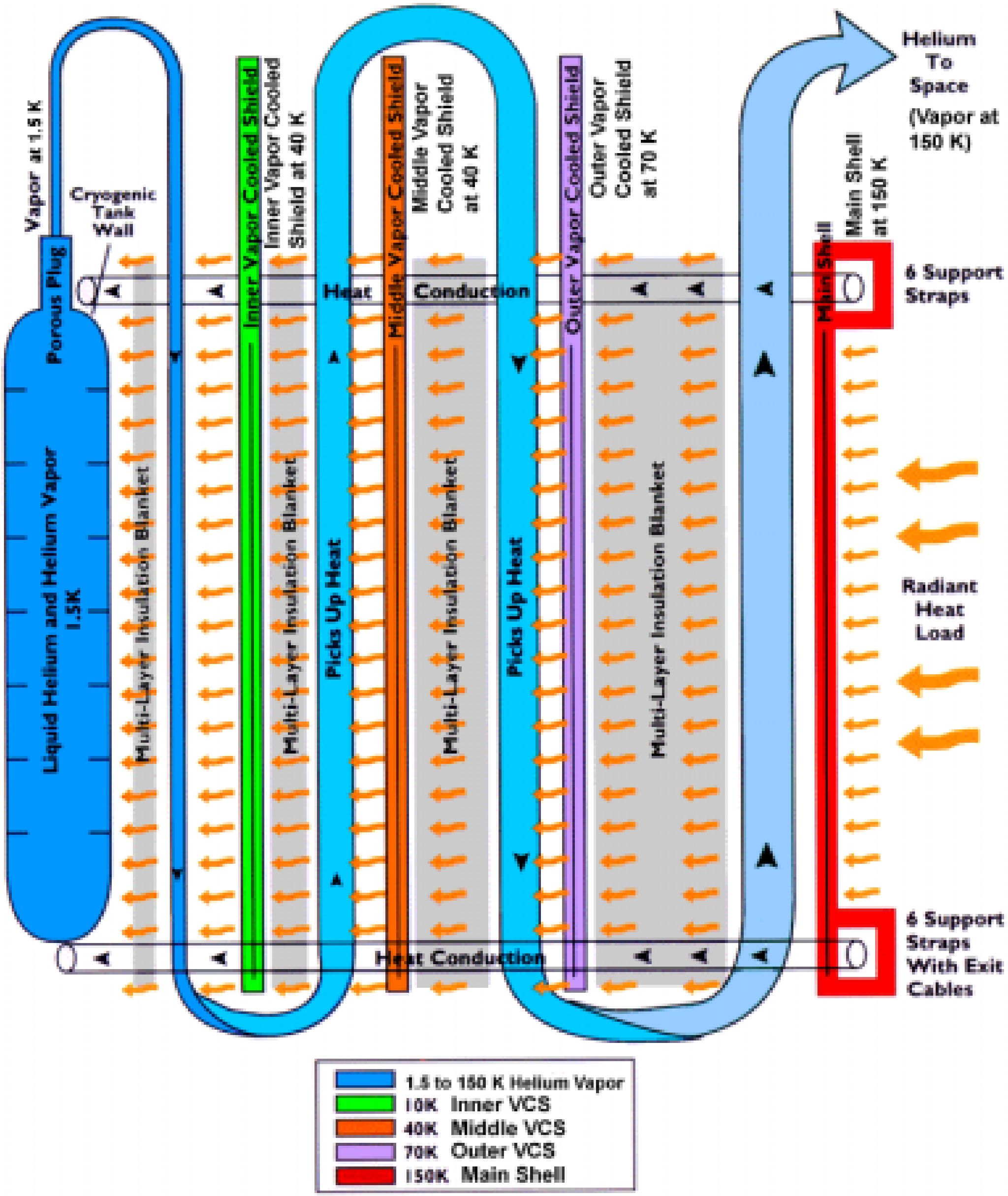
Current supply

Cryogenic safety

Storage and handling (1)







Storage and handling (2)

- Multiple radiation shields
- Maximum use of enthalpy of gas
- Phase separation in zero gravity

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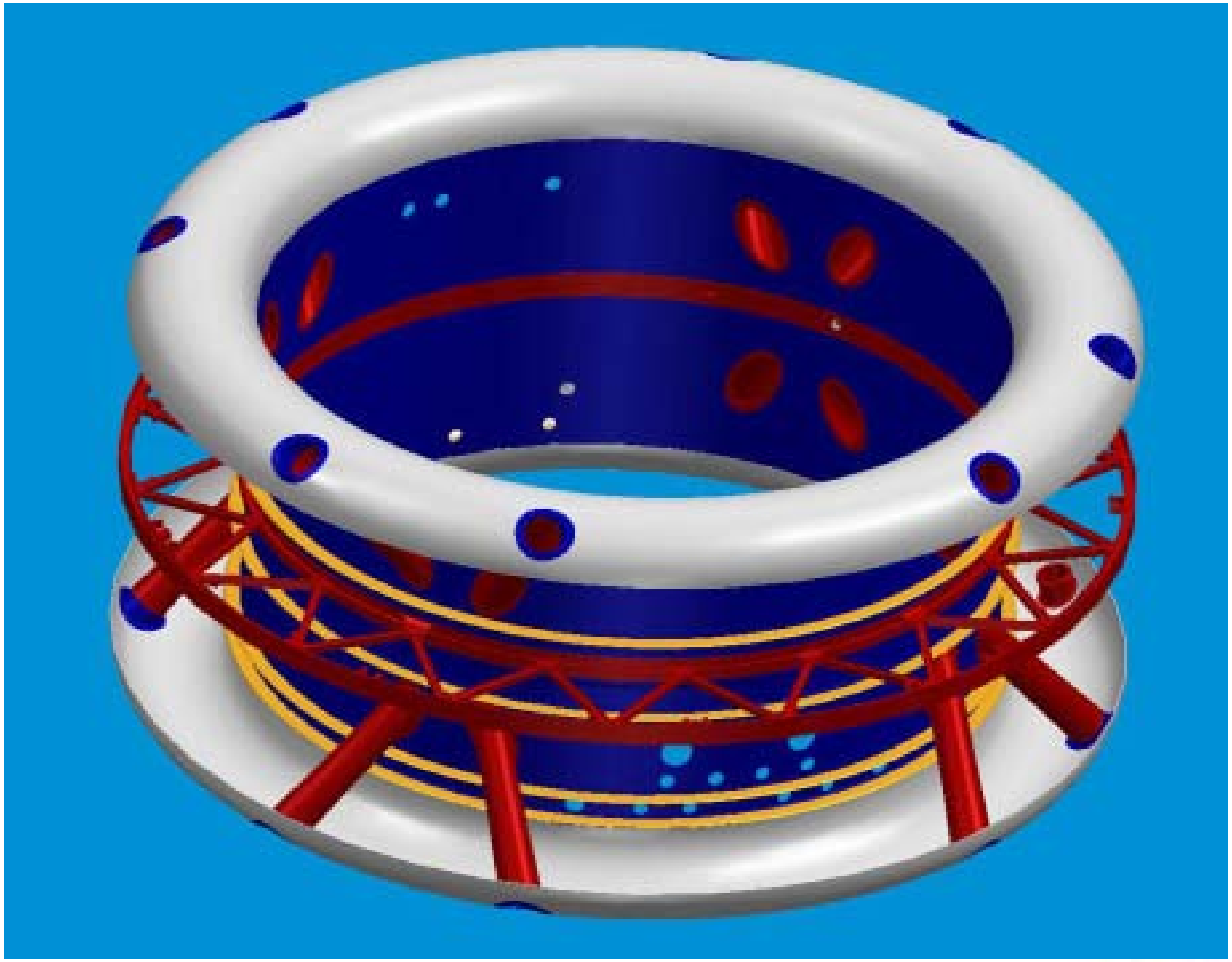
Superfluid helium vessel



2500 litres

Fully welded aluminium construction

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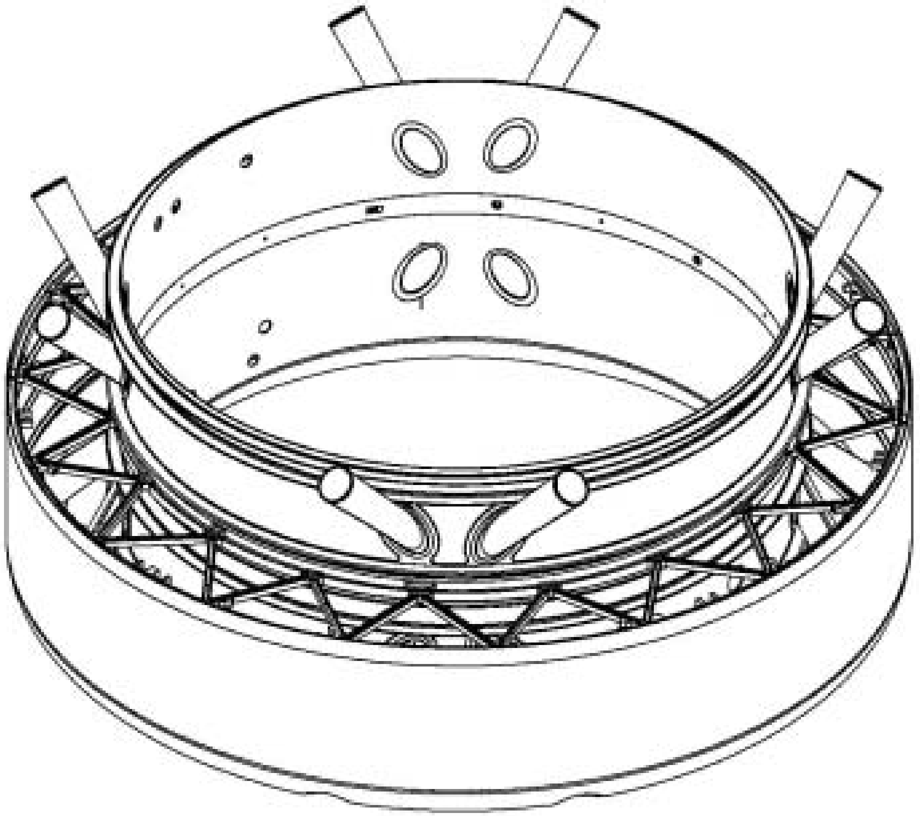
Helium vessel construction

Two aluminium cylinders with cross bracing at the centreline.

Through tubes for magnet supports.



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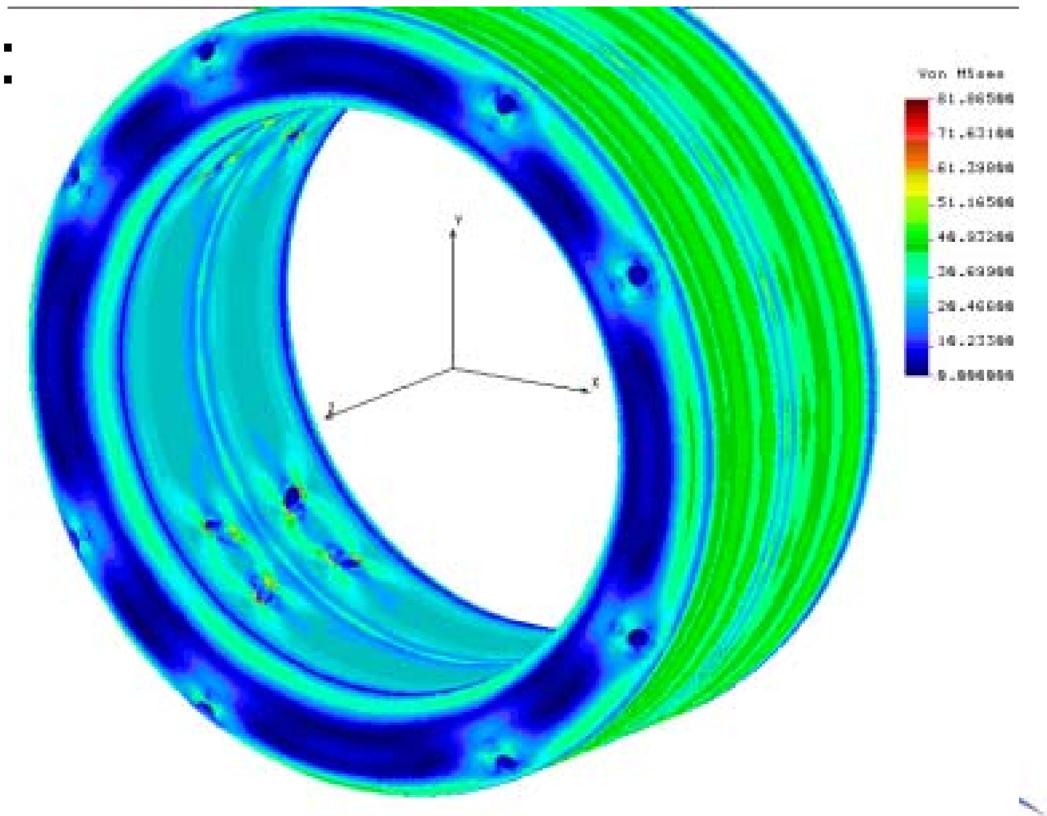
Helium vessel analysis

Detailed FE analysis has included loads due to:

- Eddy currents;
- Pressure;
- Sloshing;
- Launch/landing with tank
  - cold or warm
  - 0, 50% or 100% full.



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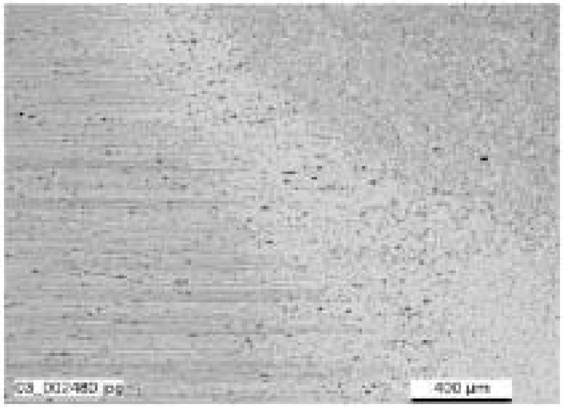
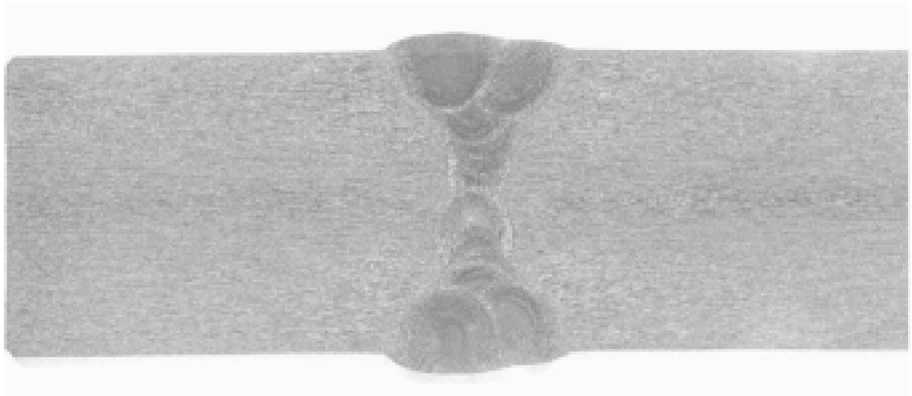
Helium vessel hardware





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Phase separator

Porous plug technology as used on IRAS, COBE, SHOOT and ISO.

AMS porous plug developed by Linde (Munich).

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Mass gauging

Calorimetric technique for determining liquid inventory.

AMS mass gauges developed by Linde and similar to ISO design.

Persistent switch

- Persistent switch allows operation of the magnet with no external current connection.
- AMS uses medical-standard (MRI) switches.

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Radiation shielding

GFRP honeycomb construction.

Heat conduction in high-purity aluminium.

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Radiation shield construction (1)

Radiation shield components under construction in Finland, the USA and England.

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Radiation shield construction (2)

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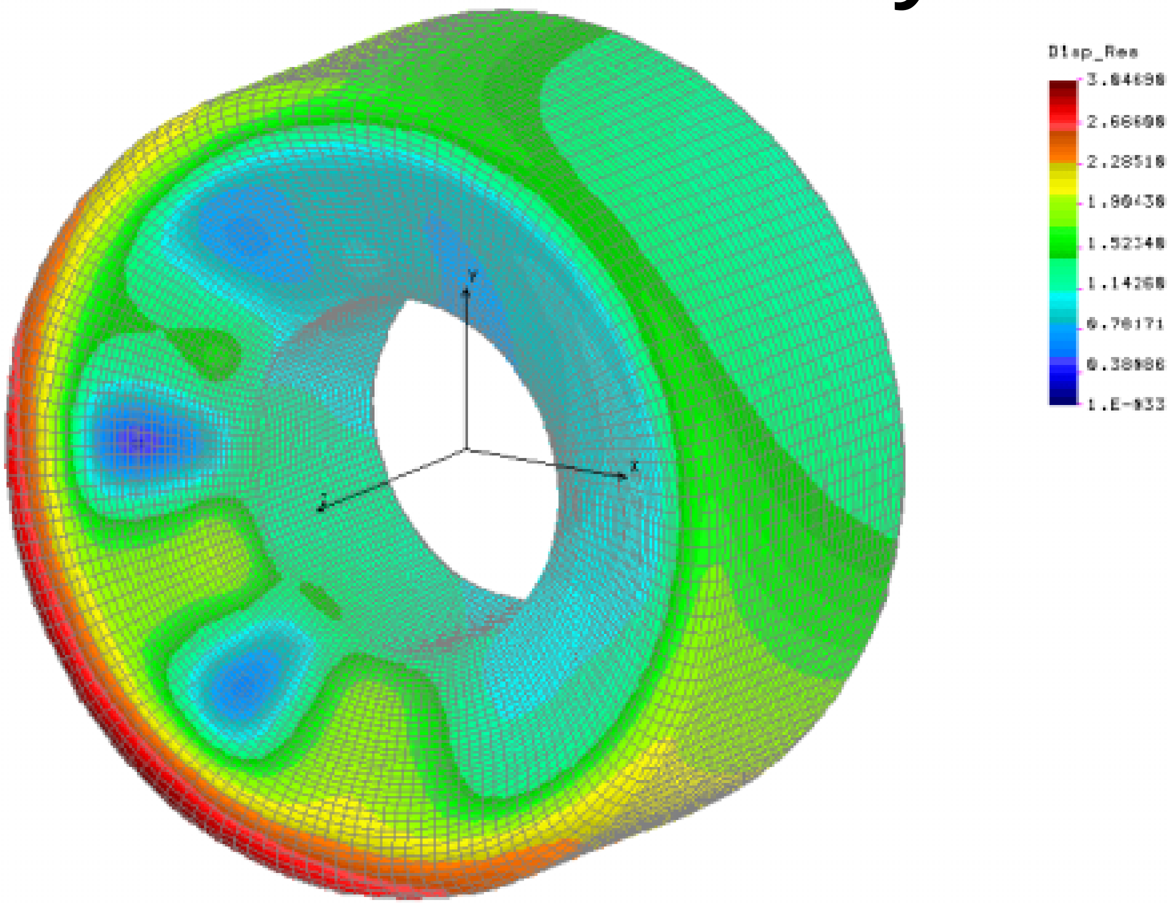
Radiation shield analysis



FE analysis on shields covers
- inertial
- thermal
- magnetic

loads.

Dipole Moments and Nominal Vent Rate

The figures on the following three slides are from a letter from Hans Hofer of ETHZ/MIT (Magnet Project Manager) to Jim Bates of NASA/JSC, the AMS Mission Manager.

Dipole Moment (1)

As agreed in 1999, AMS will provide the as-built magnetic field and dipole moment data after the flight magnet is completed.

Dipole Moment (2)

For normal, long-term operation, the AMS magnetic dipole moments will be less than:

- 100,000 A-m^2 parallel to ISS X-axis
- 40,000 A-m^2 parallel to ISS Y-axis
- 190,000 A-m^2 parallel to ISS Z-axis

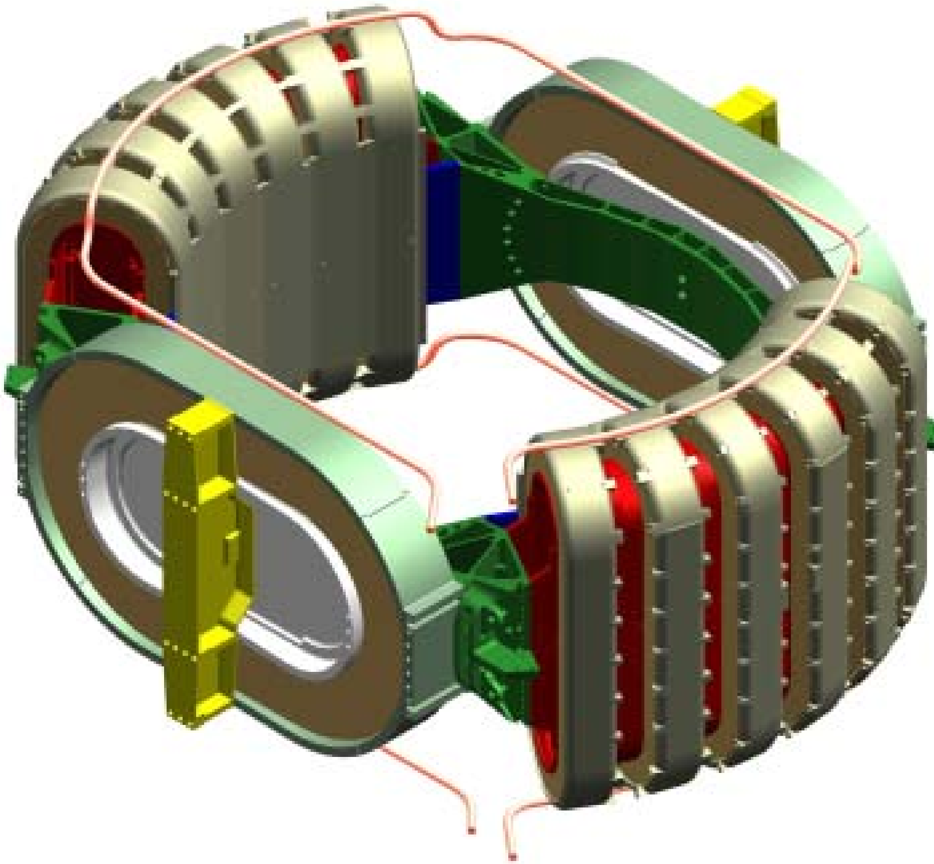
Nominal Vent Rate

The AMS-02 nominal continuous vent rate will be approximately 5 mg/s (milligrammes per second) and will exhaust via a zero-thrust vent aligned with the ISS +/-Y axis.

Coil cooling (1)

Coils are suspended in the vacuum case and cooled by conduction to the helium vessel.

Coil cooling (2)



- Heat is removed from the coils at thermal intercepts connected to a thermal bus.
- The thermal bus contains superfluid helium with very high conductivity.

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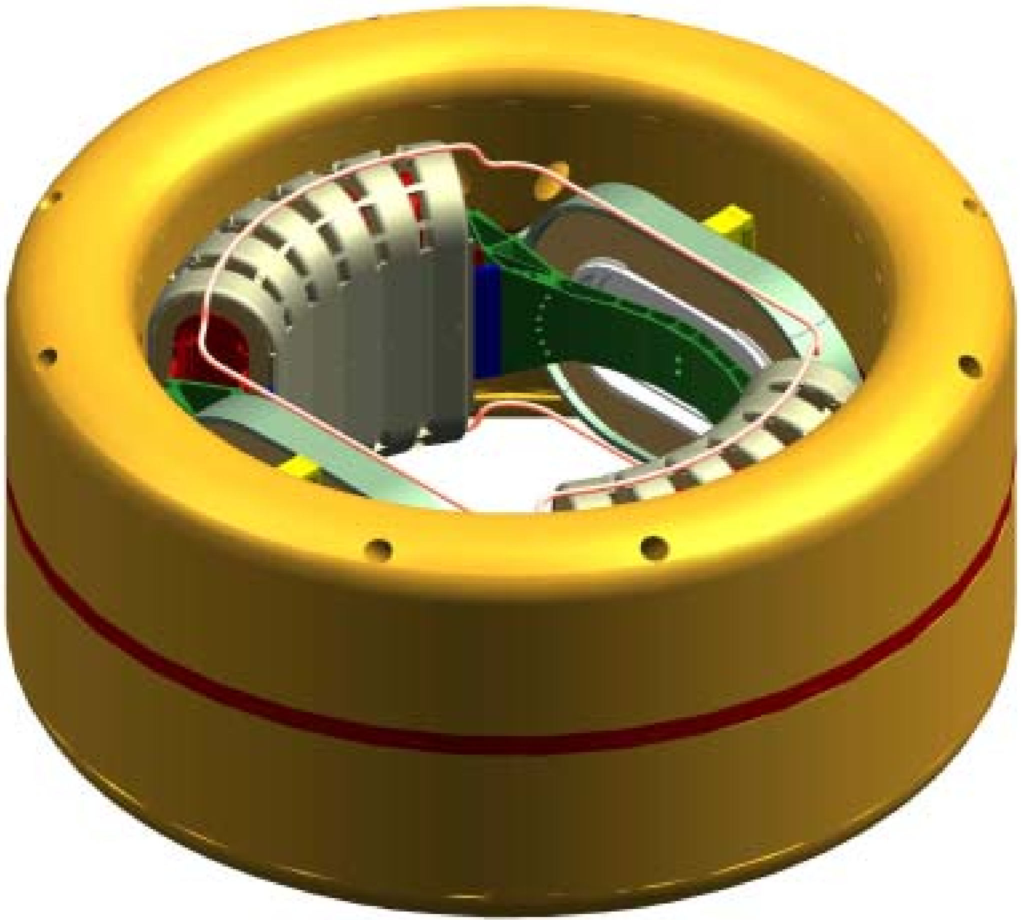
Coil cooling (3)

The thermal bus is connected to a heat exchanger in the helium tank.



Coil cooling (4)

This cooling technology was developed specially for AMS.

Experimental work in 2001 showed the system worked as predicted.

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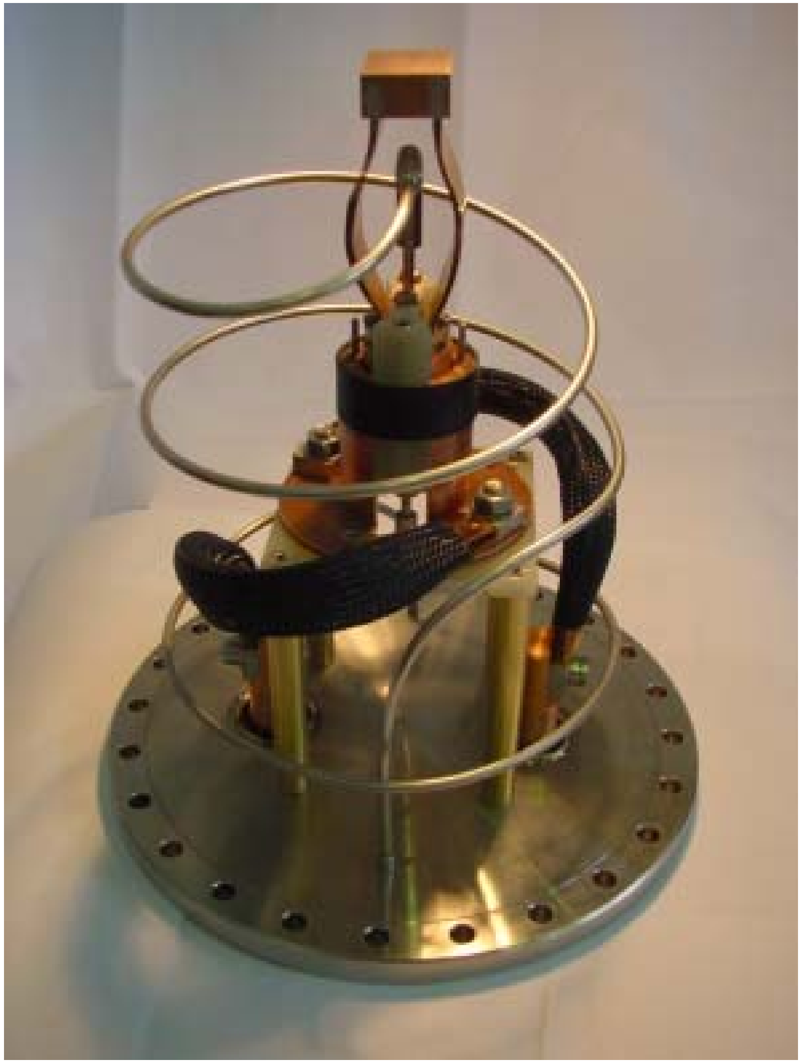
Current supply (1)

AMS operates at currents up to 459 A.

Conventional superconducting magnet current leads are bulky, heavy and consume large quantities of liquid helium.

Current supply (2)



A new type of lead has been developed for AMS, incorporating a mechanical disconnect and a thermo-mechanical pump.

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Current supply (3)

The disconnect allows the leads to be thermally decoupled when not in use.

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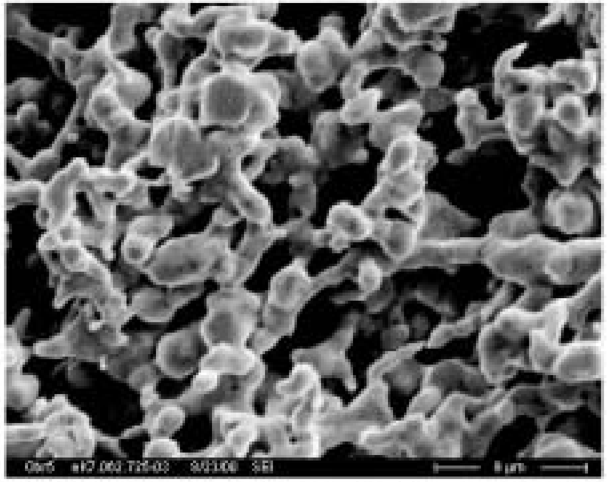
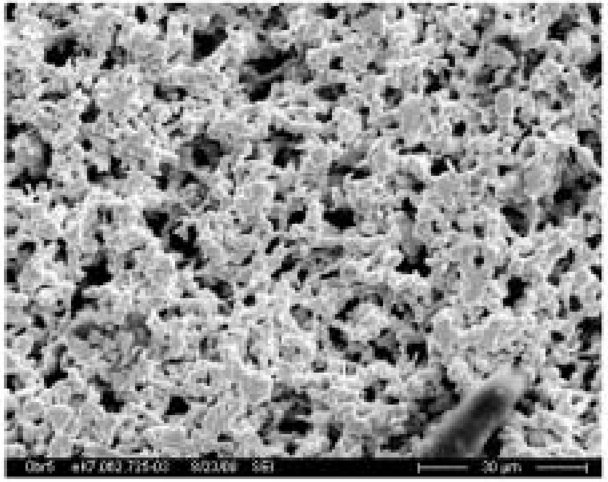
Current supply (4)

The thermo-mechanical pump (TMP) is used to cool the leads with helium during charging.

Current supply (5)





The TMP consists of a filter, heater, housing and instrumentation.

A TMP has NO moving parts.

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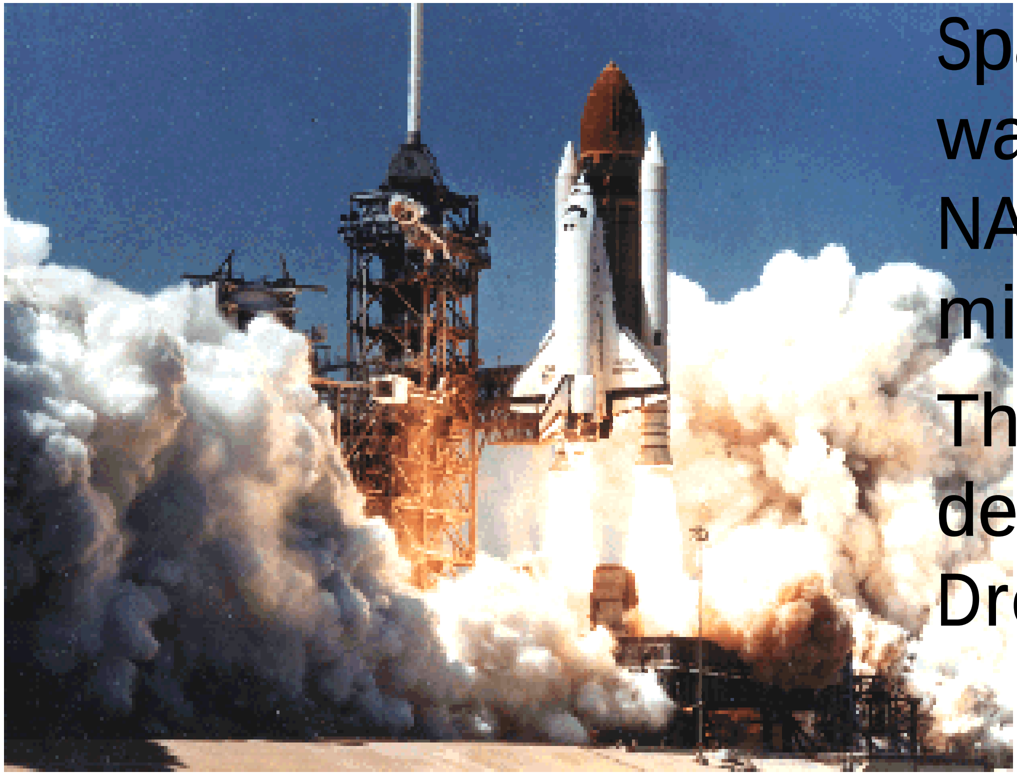
Current supply (6)



- Space TMP technology was first developed by NASA for the SHOOT mission in 1993.
- The AMS TMP is under development at ILK Dresden, Germany.

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Cryogenic safety

Extensive thermodynamic analysis and testing has been carried out to prove that the system is safe.

The challenge

Rupture of the vacuum case on the ground could lead to air leakage into the vacuum space.

This can result in high heat loads to the superfluid helium and rapid venting of gas.

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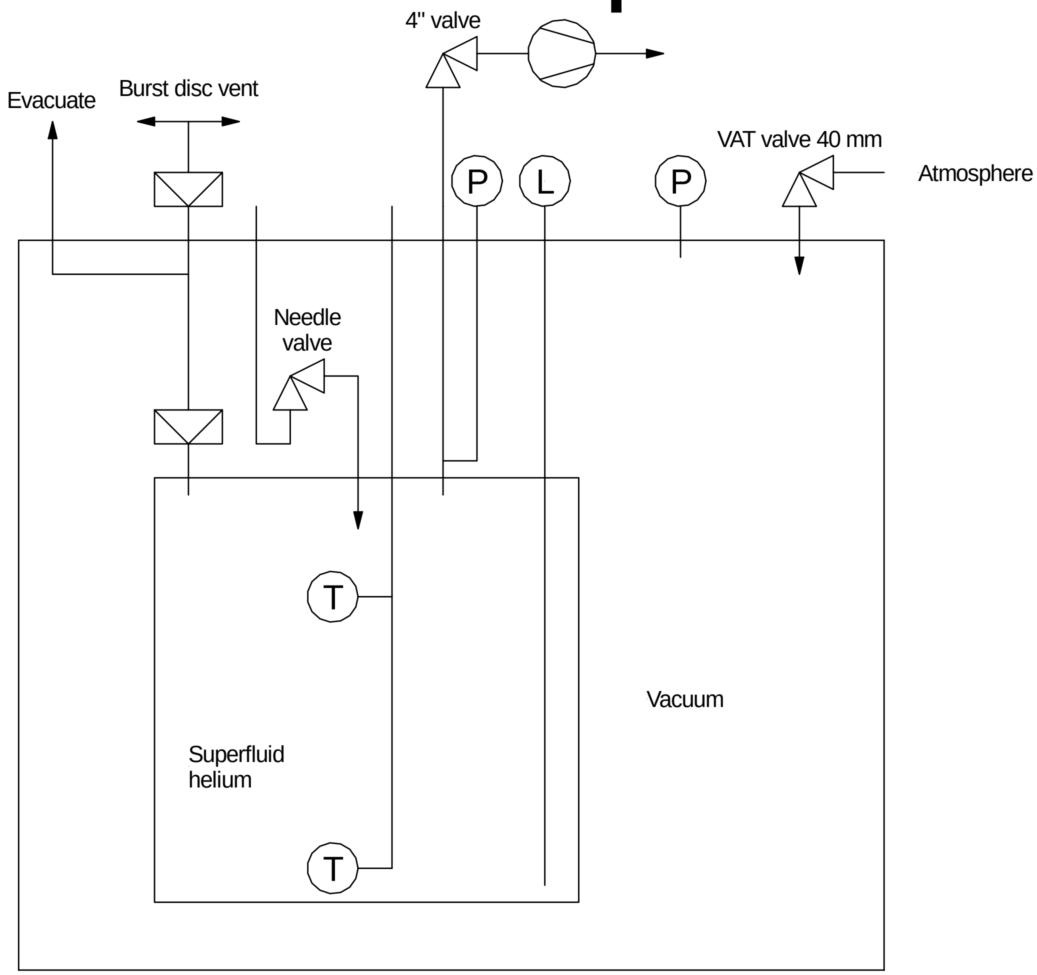
Analysis

Standard compressible flow equations cannot be used because helium is not an ideal gas at low temperatures.

But the theory can be applied from first principles if the heat flux is known, giving pressurisation, temperature rise and venting rate.

Experiments



A test facility has been constructed to measure:

- Temperature rise;
- Pressure rise;
- Venting rate.

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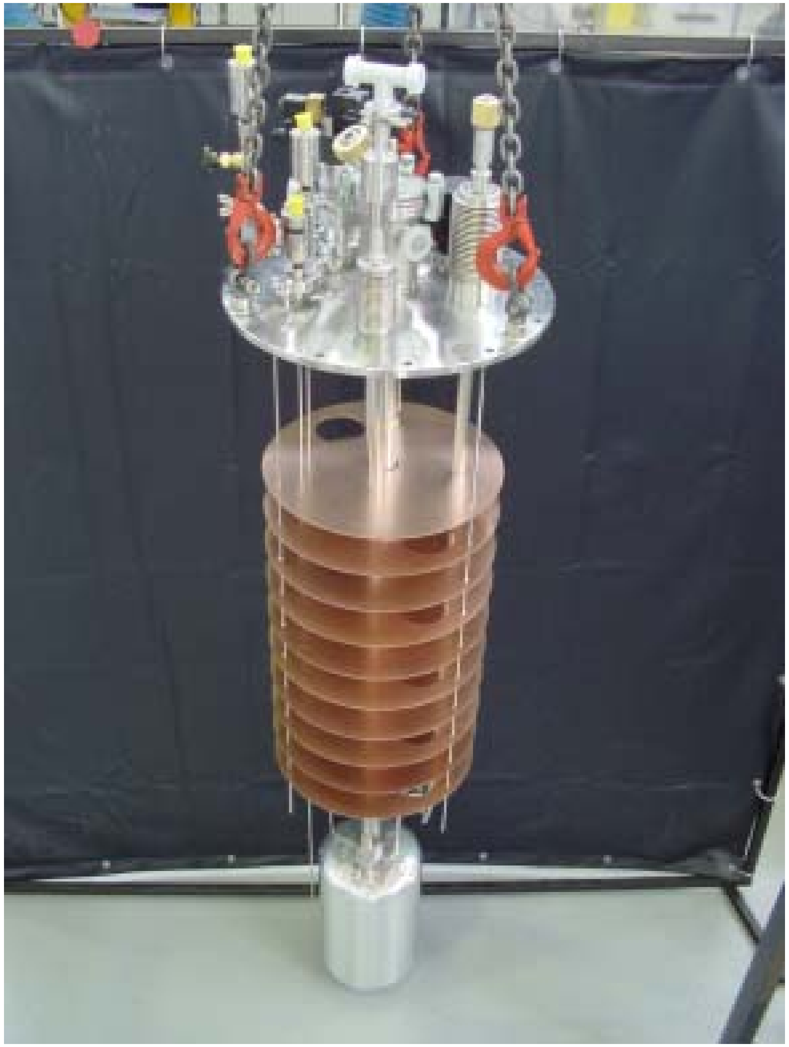
Test facility



Small (12 litre) superfluid helium vessel;

Fast acting vacuum release valve;

Temperature, pressure, liquid level, vacuum and mass monitoring.

Cryogenic insulation

- Thermal insulation supplied by CTD (Colorado) to reduce heat flux.
- Applied as 3 mm thick conformable tiles.

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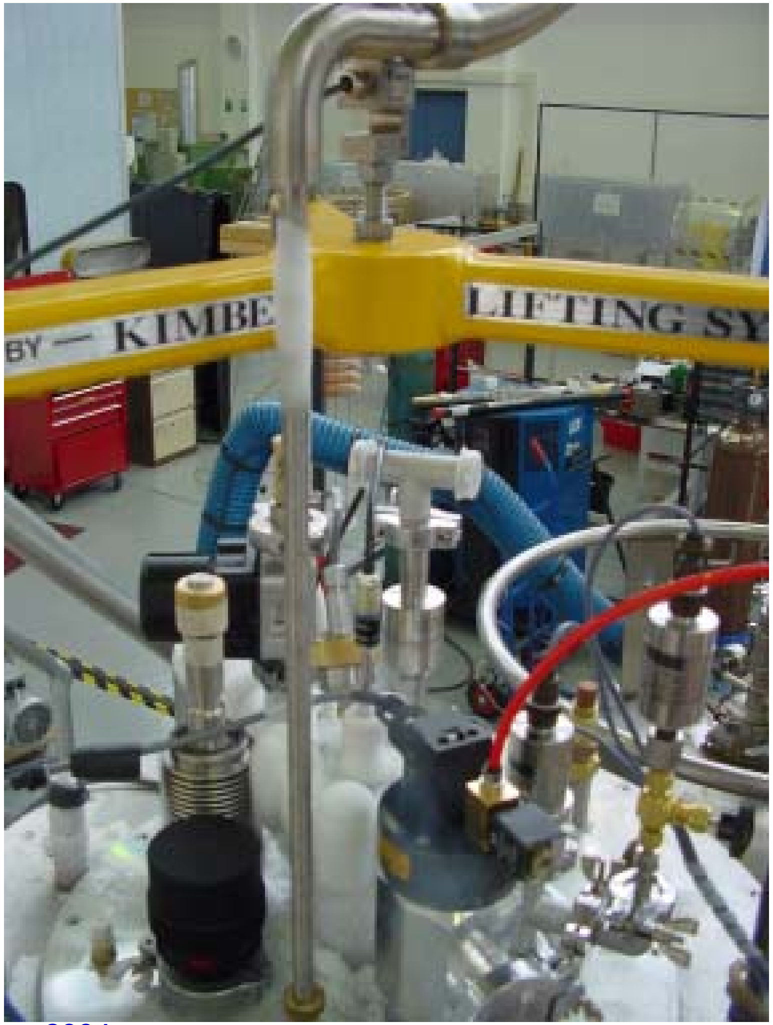
Experimental procedure



Test vessel filled with liquid helium at 4.2 K;

Pumped down to 1.8 K;

Topped off and pumped down again.

Breaking vacuum

Vacuum valve opens in 120 ms.

Helium pressurises then vents from the cryostat.

Venting rate inferred from the loss of mass of the system.

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Results

Results of experiment and analysis published at the 17th International Magnet Technology Conference (Geneva, 2001).

Heat flux with no insulation 36.0 kW/m^2.

Heat flux with insulation 4.4 kW/m^2.

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Failure scenarios (1)

On the ground

- Sudden catastrophic loss of vacuum is conceivable during ground handling.
- Helium tank will be insulated to minimise venting rates and reduce the size of vent pipework.

Failure scenarios (2)

In the Shuttle payload bay

- No credible scenarios have been identified which could lead to vacuum tank rupture once the Payload doors are closed.
- System is designed to be safe if two of the O-rings are damaged in two places, using experimentally-determined heat fluxes.

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Failure scenarios (3)

On the International Space Station

Vacuum case is irrelevant.

Pressure relief (1)

- Cryogenic pressure relief valve protects against blockage in the porous plug.
- This is for mission success only.
- Valve supplied by Linde, similar to valves used on ISO.

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Pressure relief (2)

Primary pressure relief for the system is given by burst discs.

Burst disc selection and qualification has been in conjunction with the JSC safety panel.

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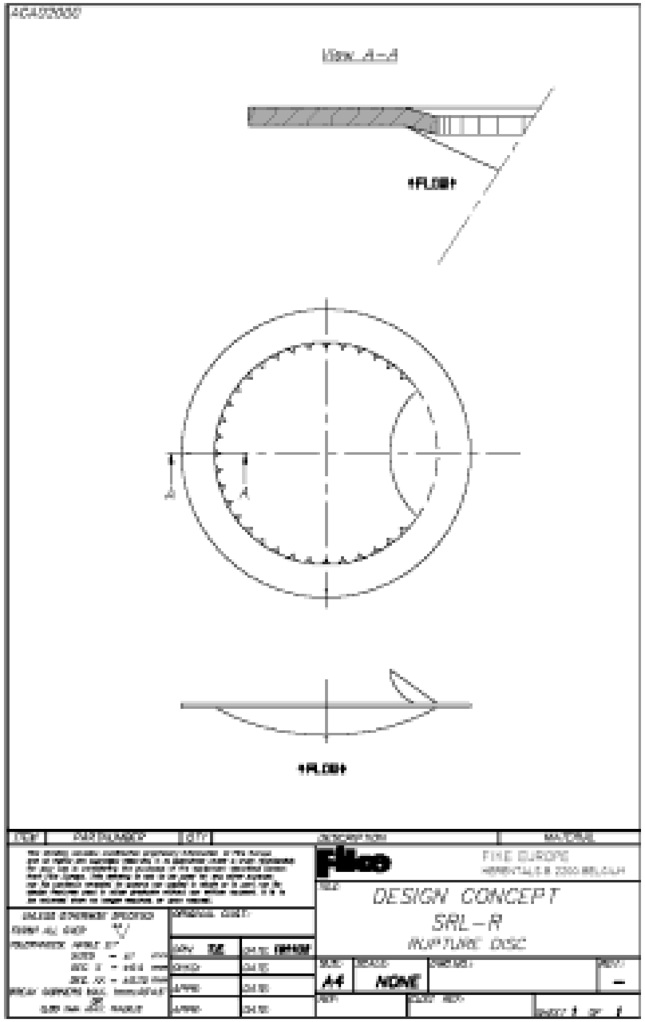
Pressure Relief (3)



Burst disc is reverse-buckling with a peripheral score and cutting teeth in the vent ring.

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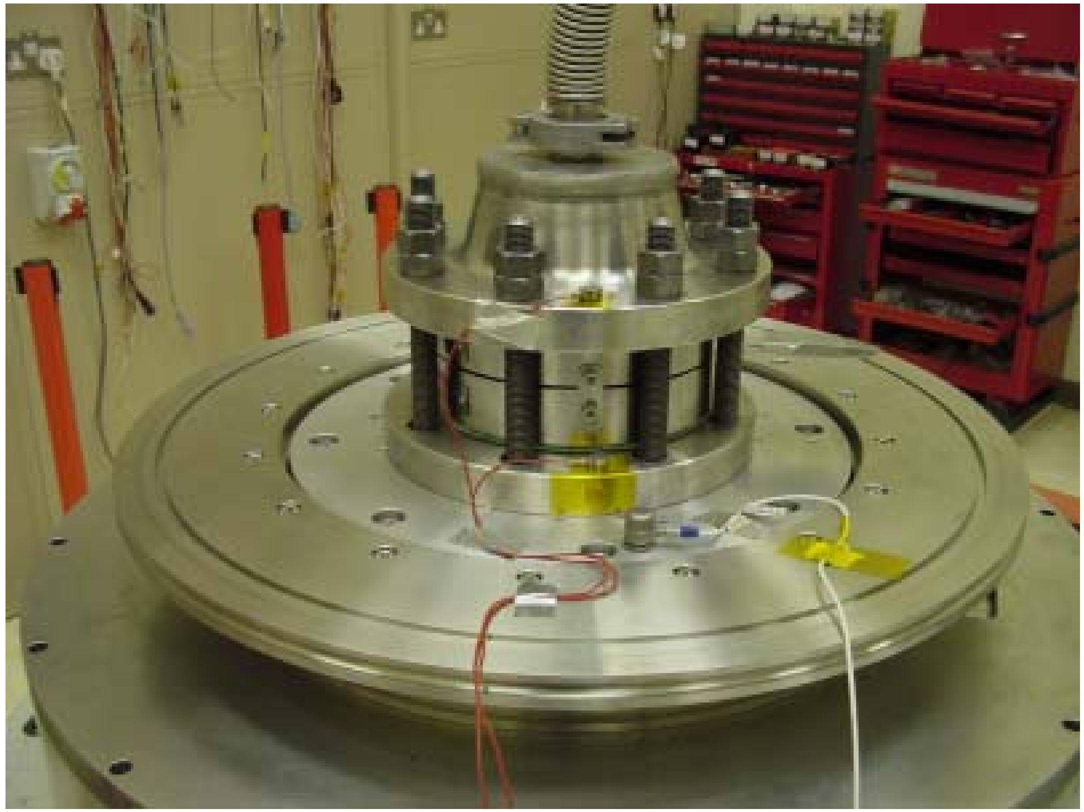
Pressure Relief (4)

Deliberate burst of a peripherally-scored disc.

Pressure Relief (5)

Peripherally scored discs from Fike have been successfully leak tested and vibration tested. There was no degradation of the leak tightness after vibration.



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Cryogenic safety - conclusions

The cryogenic system has been shown to be safe in all credible circumstances by analysis and experiment.

The NASA Safety Panel accepted these analyses and experiments in a meeting on 17 January 2003 in Houston.

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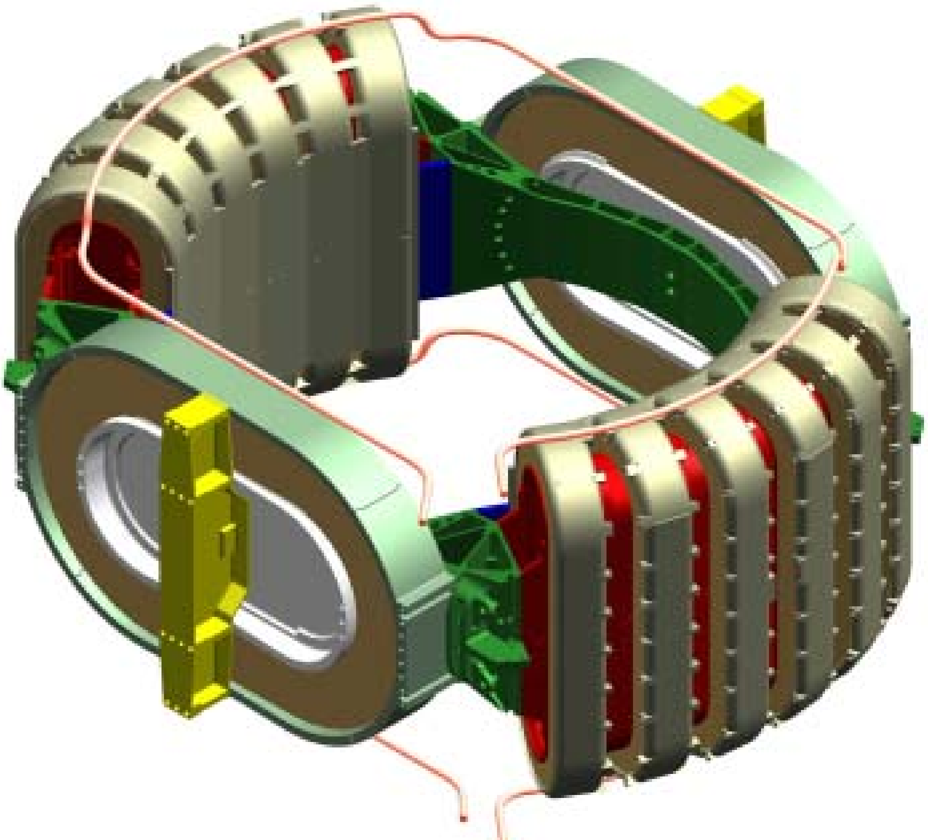
Mechanics

- Magnetic forces and supports
  - Magnet structure
- Inertial forces and supports
  - Straps

Magnetic forces

Magnetic forces much higher than inertial forces but:

- Loads never superimposed;
- Loads reacted internally;
- Thoroughly tested on the ground.



Magnetic force analysis

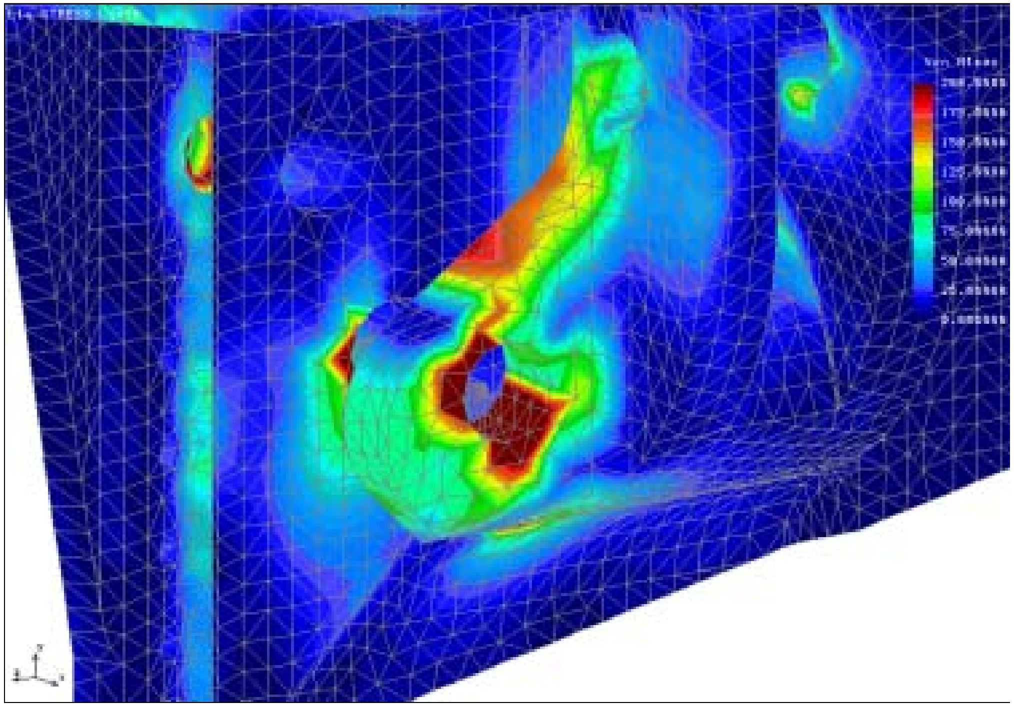
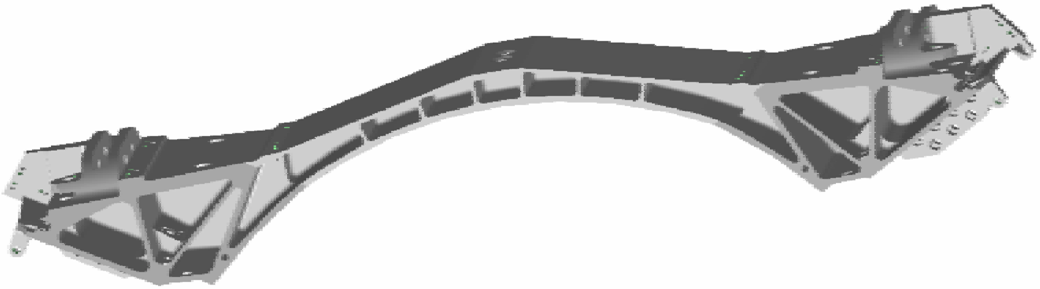


Figure 5 - Von-Mises stress results for secondary case 8

- FE analysis of magnetic loads.
- FE analysis of stress and deflection in structural components.

Structural Components



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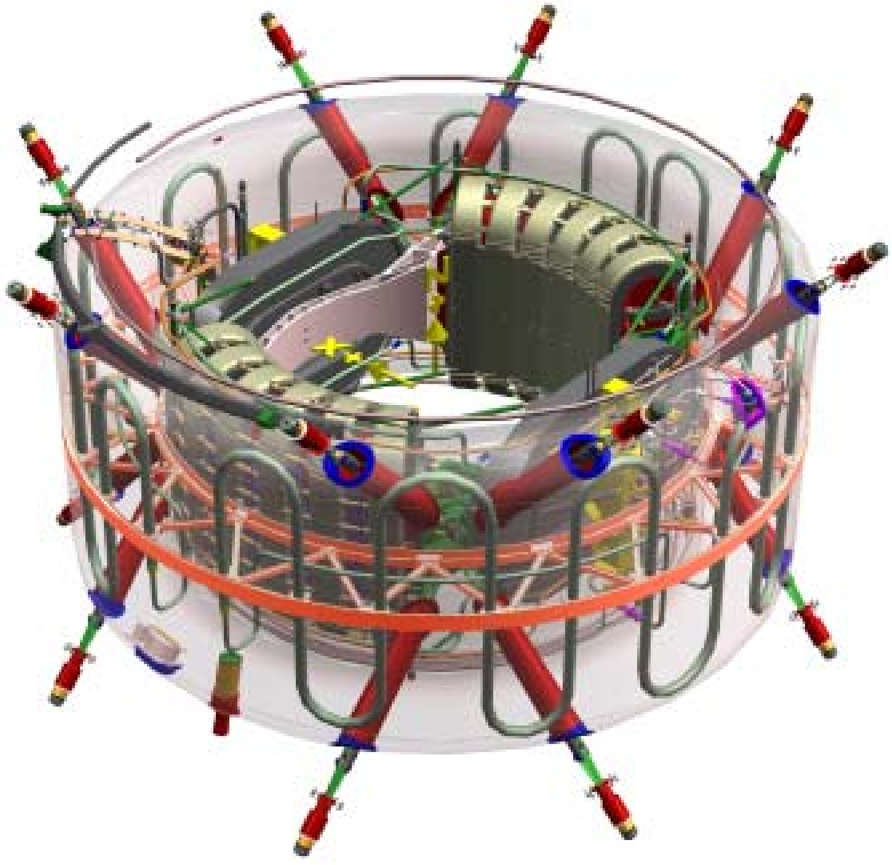
Inertial forces

Inertial forces on the magnet are supported from the vacuum vessel by a system of 16 straps.



Strap design (1)

Straps are designed for minimum heat leak, maximum strength and maximum stiffness.

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Strap design (2)

The straps are made in several parts to make the best use of material properties at different temperatures.

Strap design (3)

This also allows the attachment of intermediate heat sinks at metallic bearings.

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Strap design (4)

The straps have a passive orbital disconnect feature which reduces the heat load on orbit.

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Strap manufacture

Straps are being manufactured by CTG in England.

This company has extensive experience in the manufacturing of composite supports for medical and other applications.

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Strap analysis and test

Analysis and test results will be presented separately by Lockheed Martin.

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Magnet support equipment

Cryogenic valves

Warm valves

Cryocoolers

Avionics

Cryogenic valves (1)

Cryogenic valves supplied by Weka of Switzerland.

Actuated by helium gas pressure.

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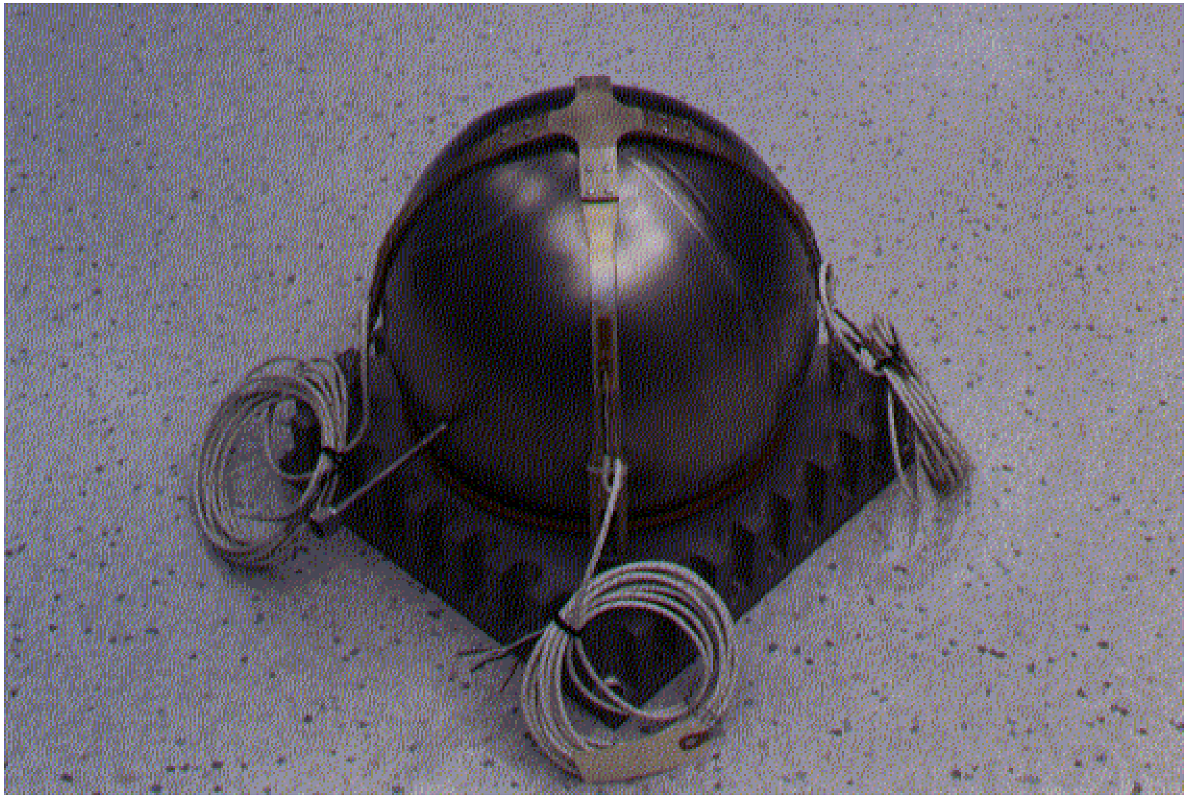
Cryogenic valves (2)



Actuating helium gas stored outside the vacuum case in a pressure bottle.

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Cryogenic valves (3)

Qualification testing for the cryogenic valves will include:

Multiple cycling at 1.8 K;

Cold vibration testing at 4.2 K.

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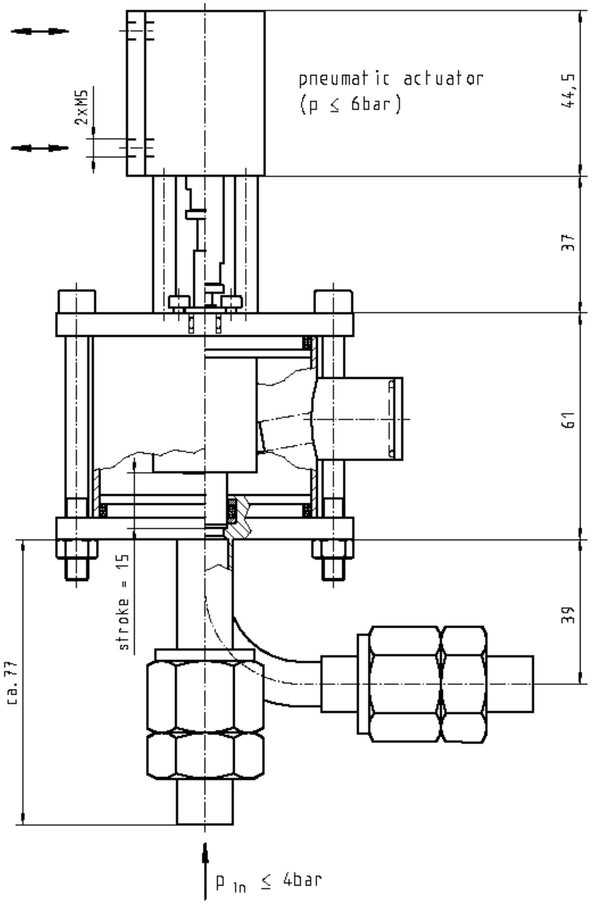
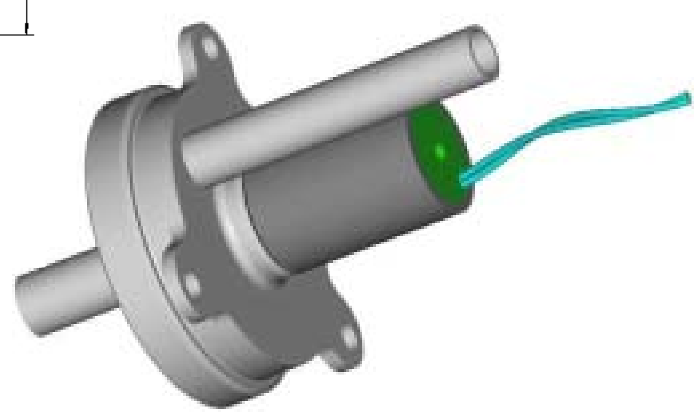
Warm valves (1)



Warm valves will be supplied either by Polyflex (England) or Weka (Switzerland).

These valves will be positioned outside the vacuum vessel.



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Warm valves (2)

Functional testing of the Polyflex valve for pressure drop and magnetic field tolerance has been carried out.

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Cryocoolers (1)

AMS has four Stirling cycle coolers connected to the outer shield.

The coolers are developed and qualified from commercial units by NASA/GSFC.

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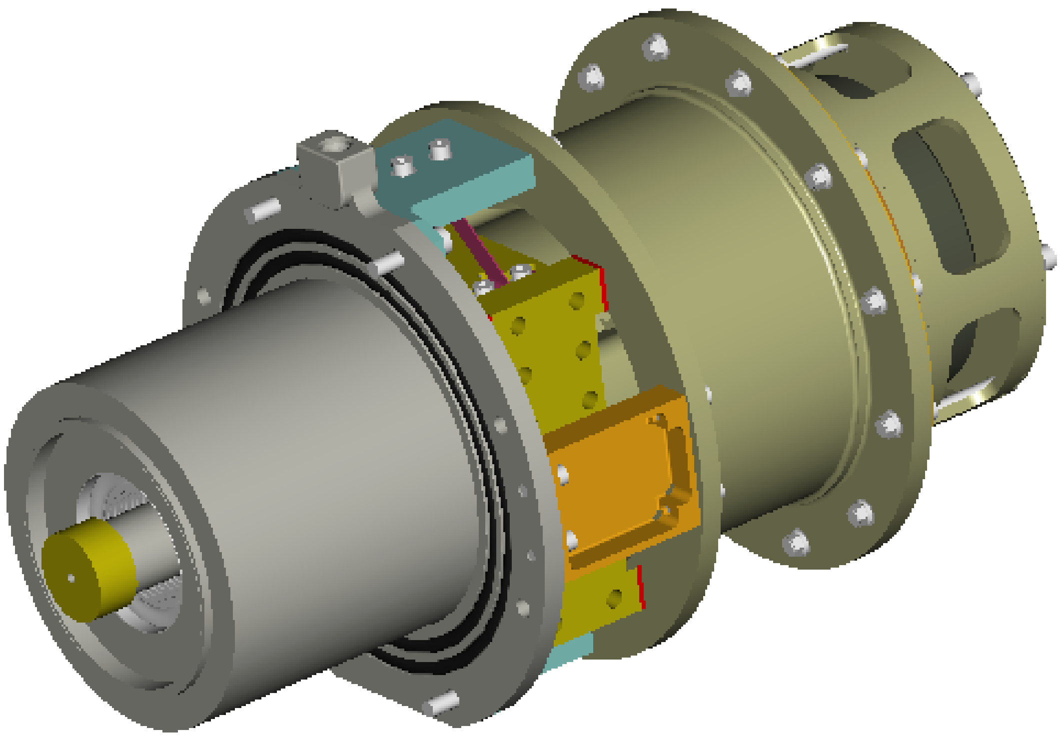
Cryocoolers (2)

Electronics by ETH.



Avionics

- Cryomagnet avionics box (CAB)
  - Magnet current source
  - Cryomagnet control and monitoring system
  - Cryomagnet self-protection system
- Designed and manufactured by CRISA (Astrium) in Spain

Magnet current source

Input ISS bus

15 A

122 V dc

Output to magnet

459 A

5 V dc

Control and monitoring system

- Monitors more than 50 cryogenic thermometers
- Measures temperatures to 1 mK at 1.8 K
- Telemetry and telecommand interface between the magnet and the AMS CAN bus

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Cryomagnet self-protection system

Detects very early onset of a magnet quench.

Ensures quench energy evenly distributed between magnet coils.

Initiates re-cooling of the magnet system.

Contains a watchdog which will discharge the magnet in case of loss of power or communications.

Uninterruptible Power Supply

Provides uninterruptible power to the Cryomagnet Self Protection system and the quench heaters.

The magnet can always be discharged, even if power, communications and ground control are lost.

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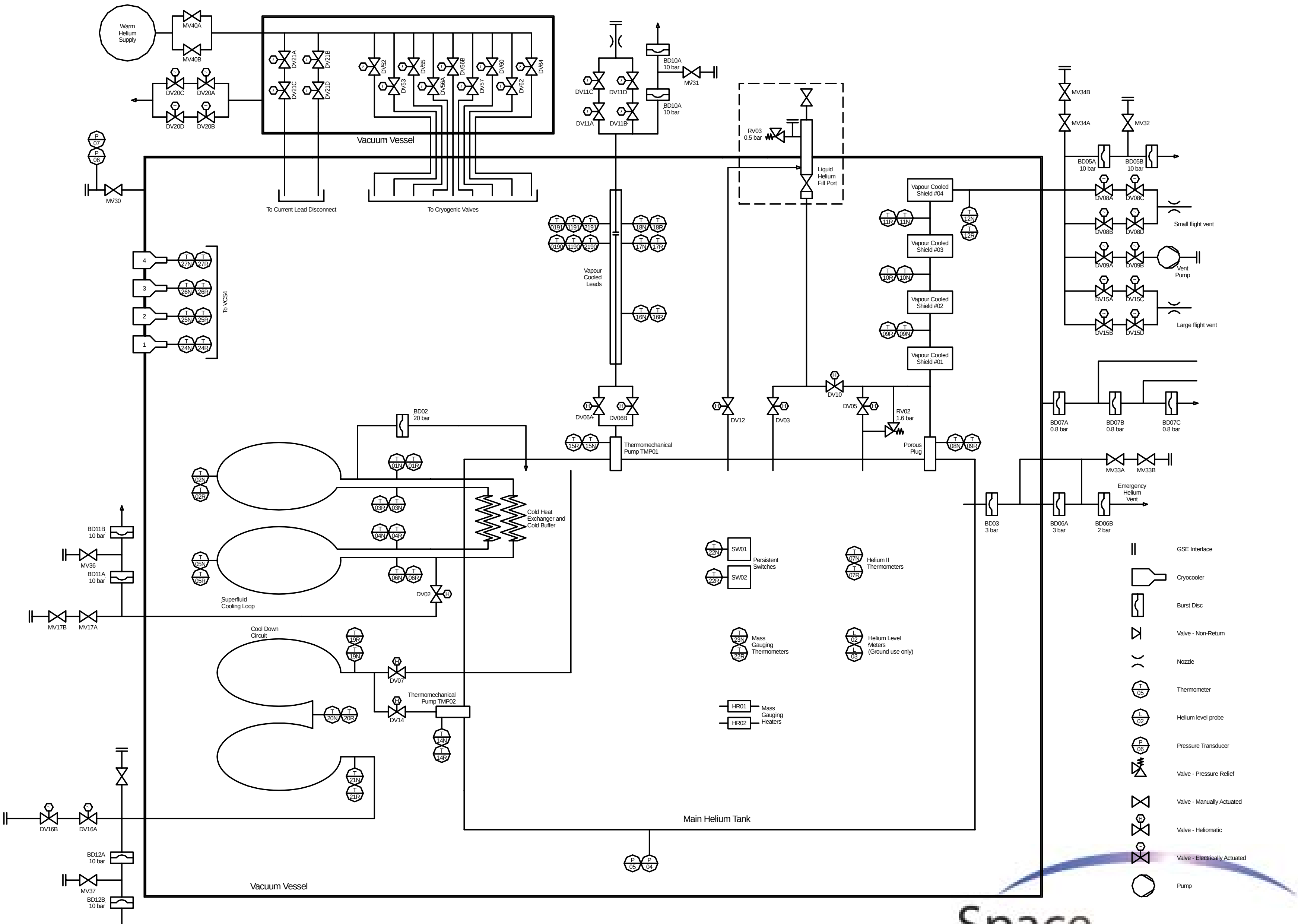
Magnet operations overview

Cool down and filling

Steady state operation

Charging

Quenching



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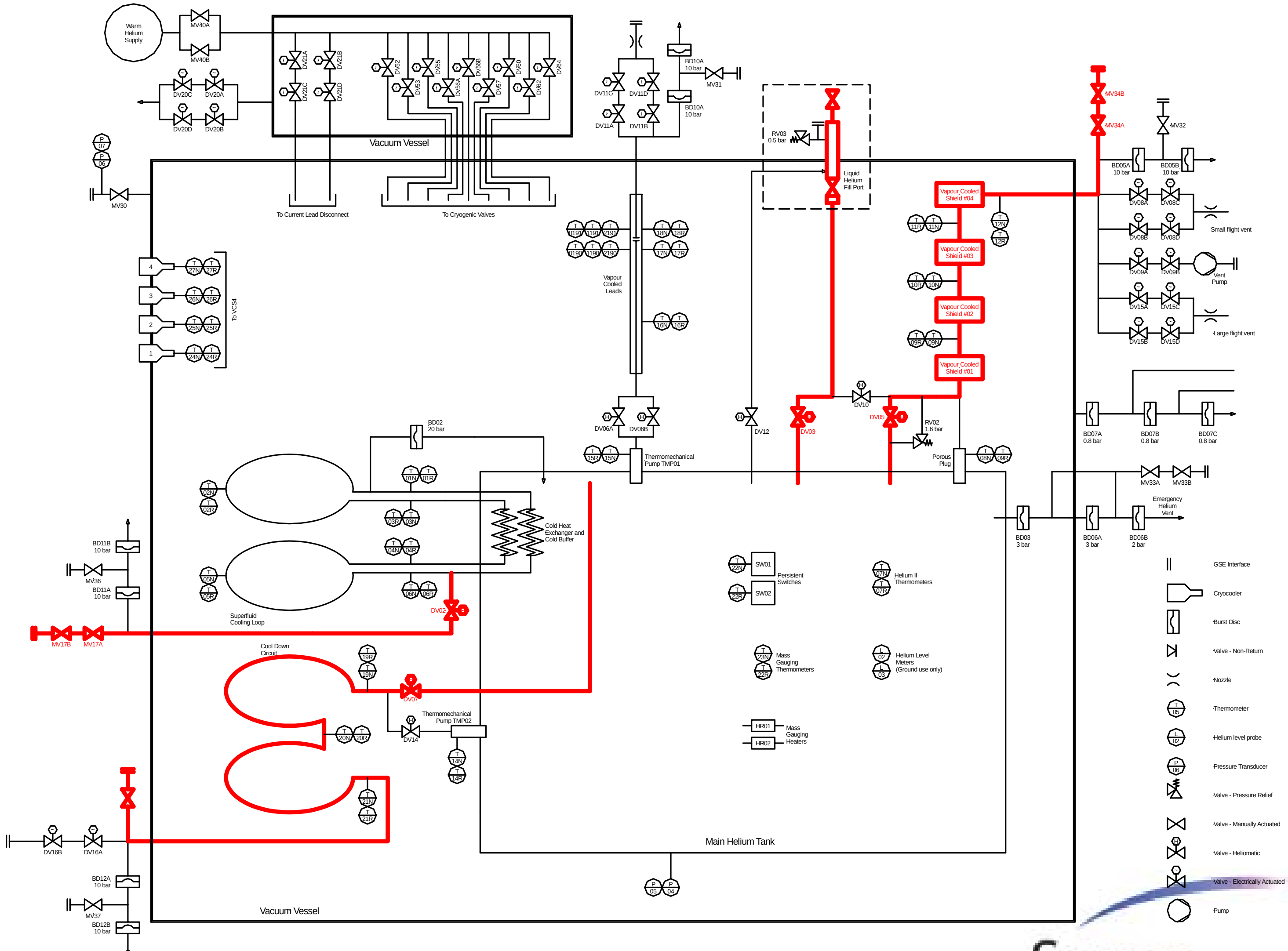
Cool down to 100 K



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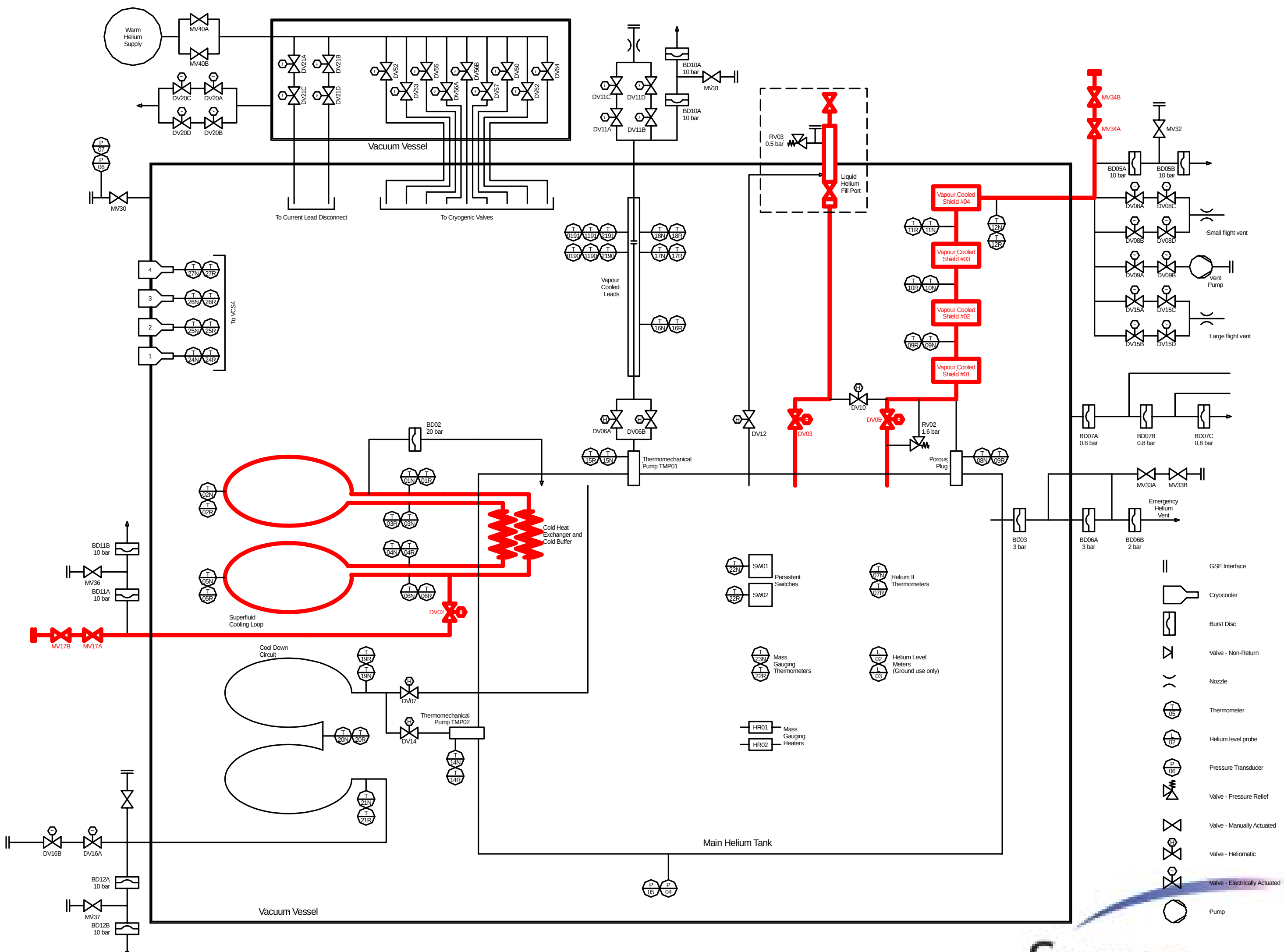
Cool down to 4.2 K



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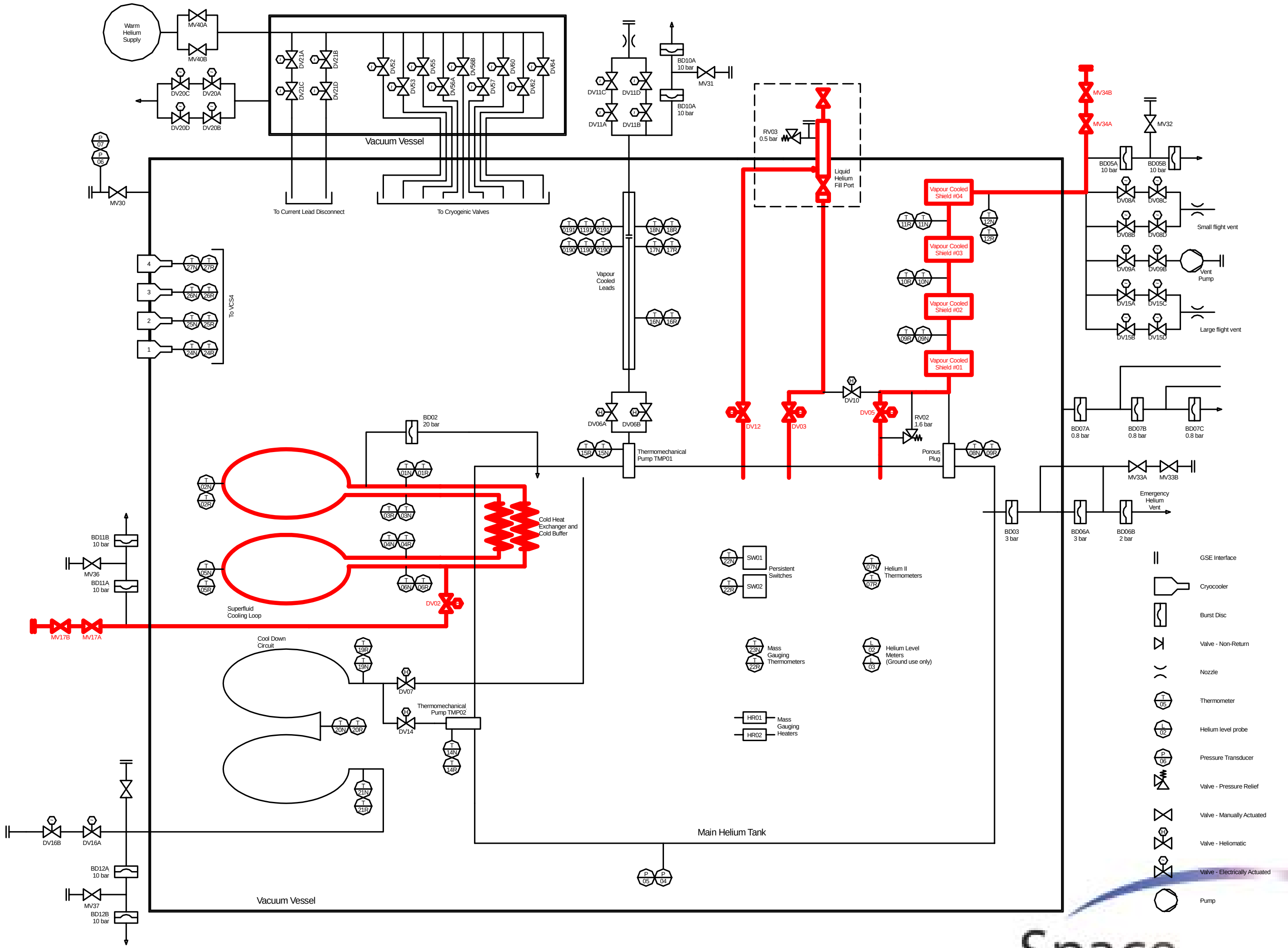
Cool down to 1.8 K



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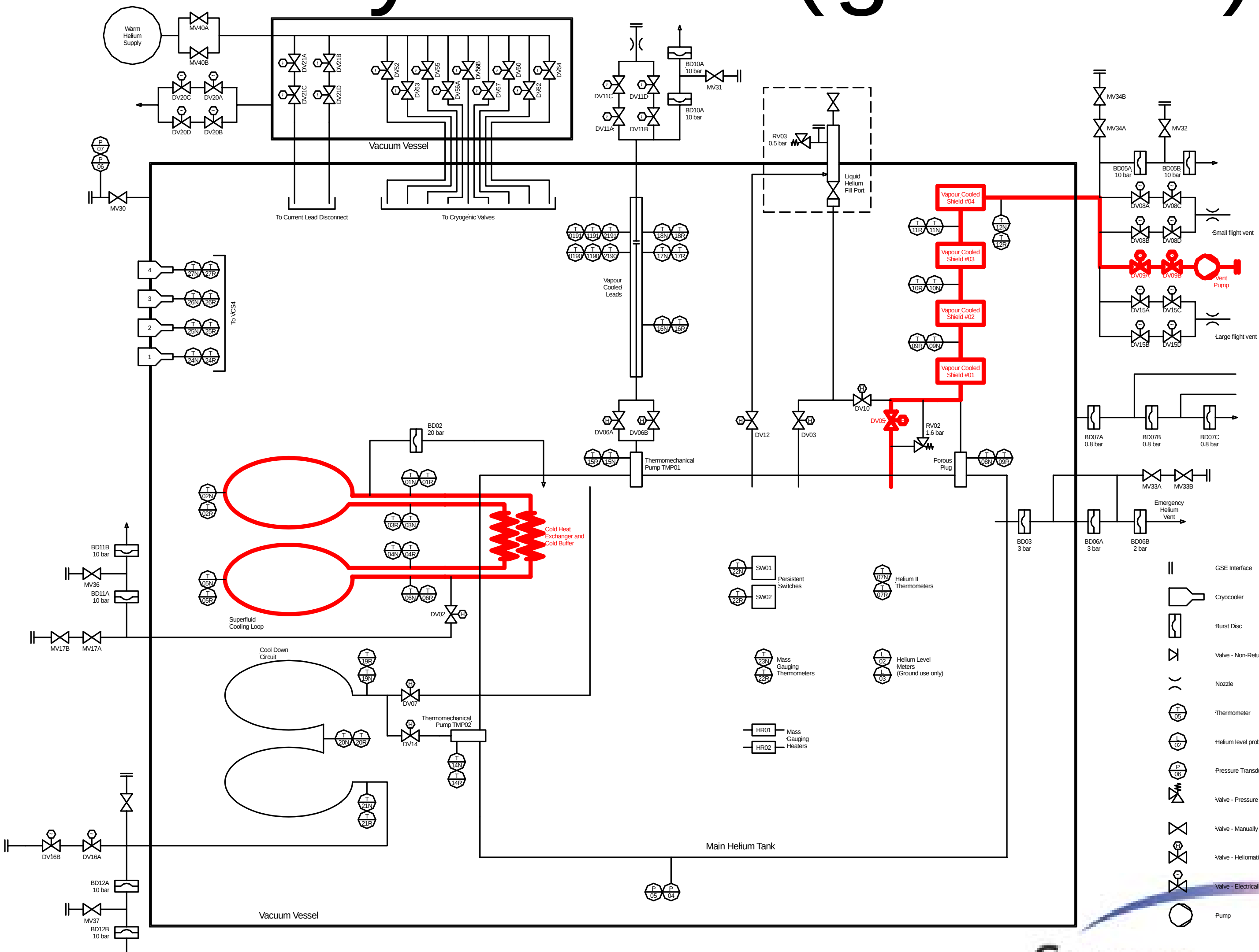
Steady state (ground)



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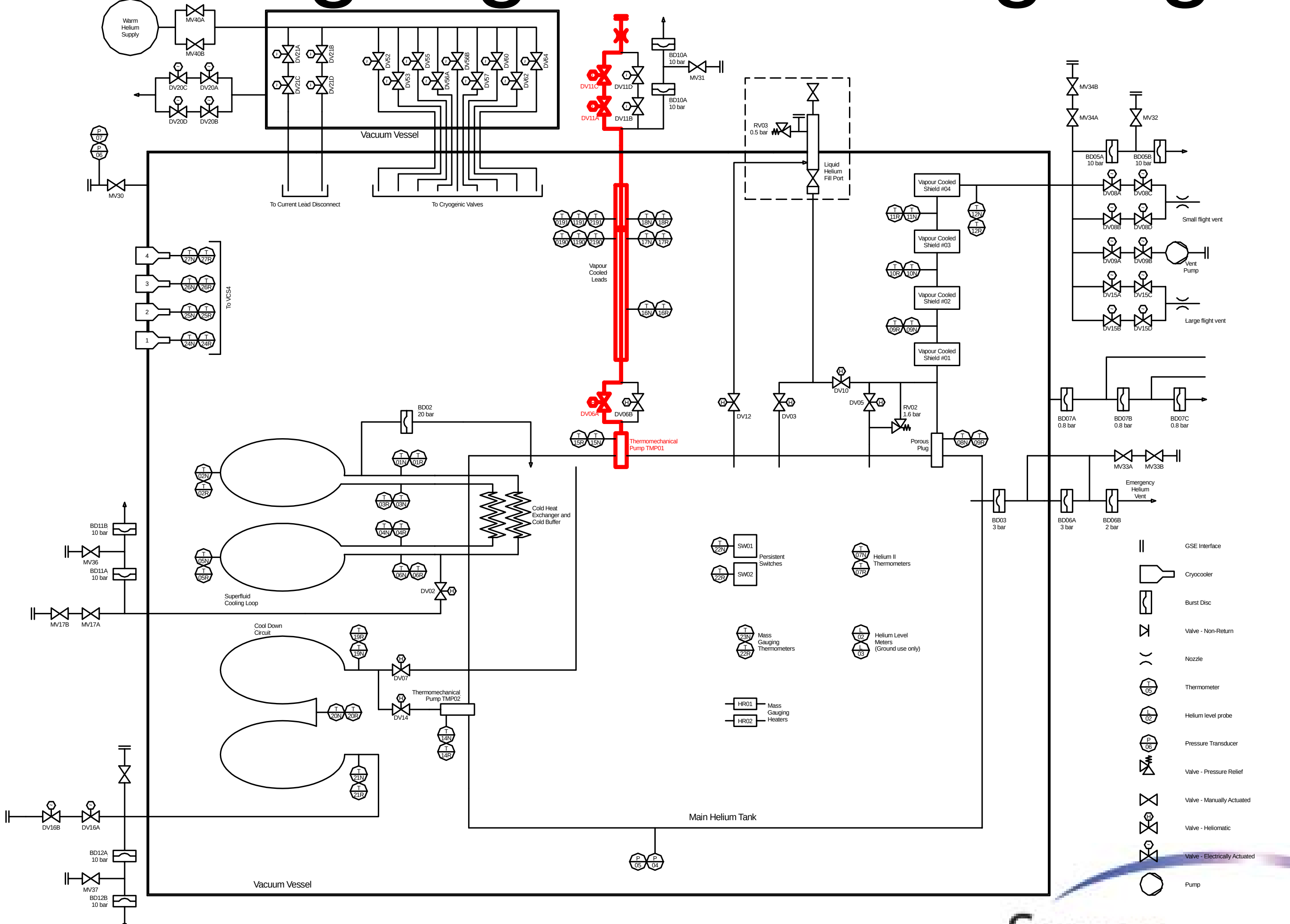
Charging/Discharging



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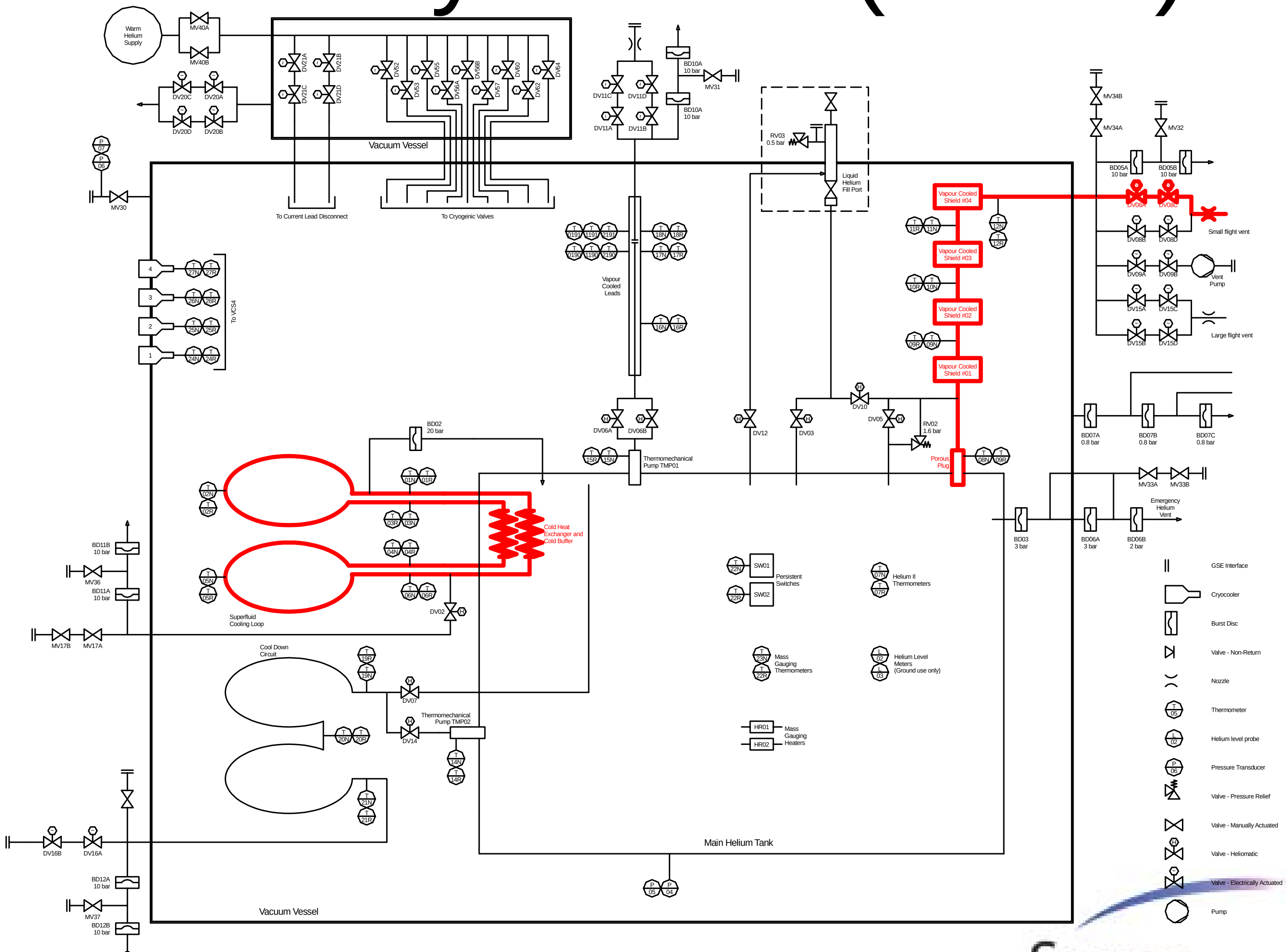
Steady state (orbit)



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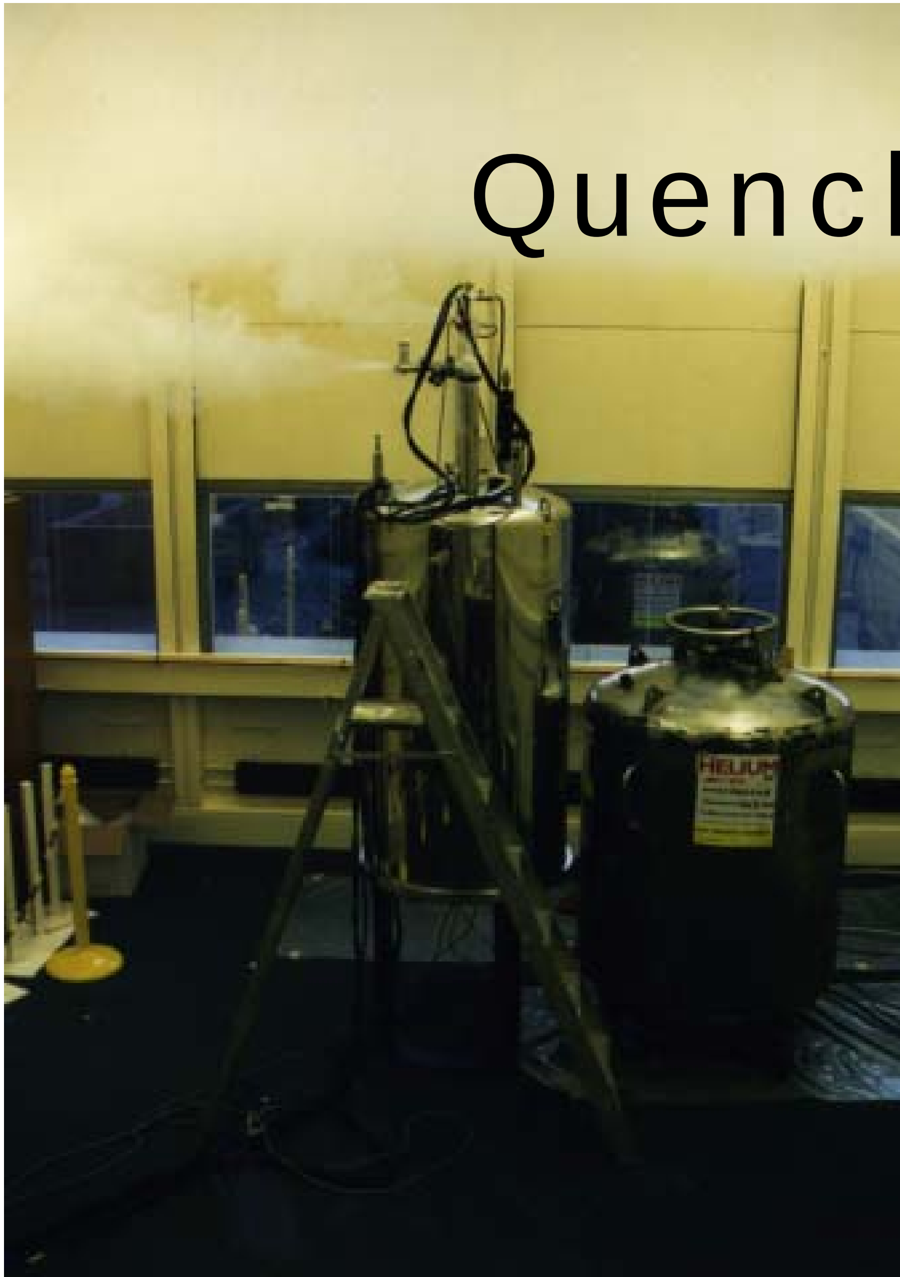
Quenching (1)

The magnet is not expected to quench in space until the liquid helium runs out at the end of the experiment lifetime.

Quenching (2)



Magnets where the coils are in direct contact with liquid helium can rapidly produce large volumes of helium vapour on quenching. They also lose all their liquid helium.

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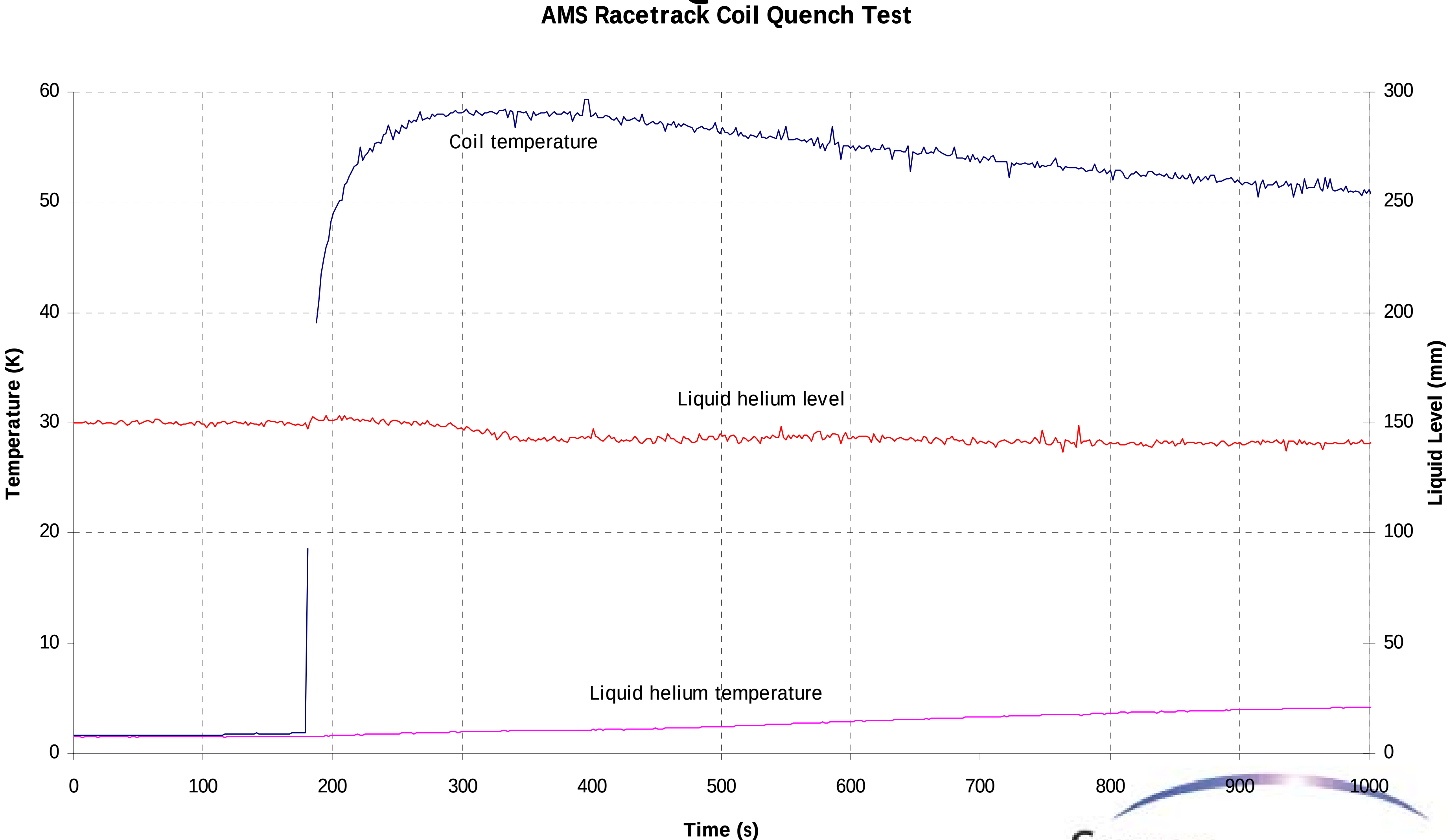
Quenching (3)

AMS must be able to be re-cooled following a quench in space with its existing helium inventory.

The AMS coils are indirectly cooled.

The cooling system limits the heat flow from the coils to the helium vessel to a manageable level.

AMS Coil Quench Test



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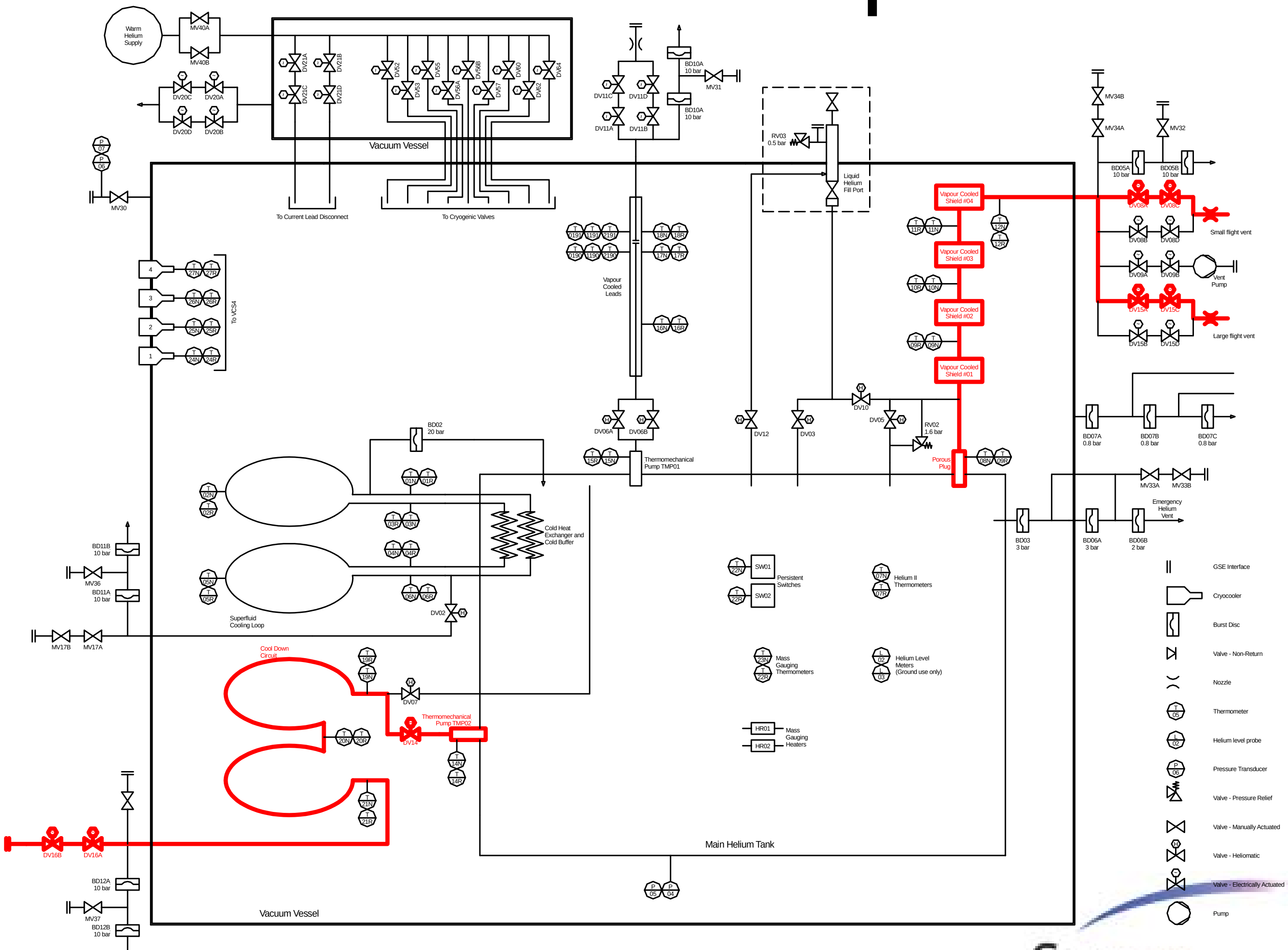
Space Cryomagnetics

Re-cool after quench



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